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16. ABSTRACT

This study was conducted to evaluate the effects of blending two or more waters of different quality and to relate their composition to the corrosive effects and calcium carbonate deposition tendency of the water on distribution systems. The EPA mobile water quality monitoring laboratory was deployed at 30 selected sites in Southern California where imported waters from the Colorado River and California aqueducts are used as delivered or blended with local groundwaters. Eighteen computer-controlled parametric systems on board the laboratory analyzed and recorded field data to assess water quality factors associated with corrosion and stability. The waters studied could be classified as having moderate to high hardness, alkalinity and total dissolved solids content.

The data were analyzed for significant interrelationships relative to pH, calcium hardness, alkalinity, dissolved minerals, corrosion rates, calcium carbonate deposition test (CCDT) results, and calculated values for the Langelier saturation and Ryzner stability indices.

For waters of similar chemical composition the CCDT results were more indicative of the benefits to be derived from pH control or zinc phosphate films for mitigating corrosion than the polarization corrosion rates.

Cost comparisons for corrosion control by use of caustic soda to adjust pH and zinc phosphate as a corrosion inhibitor were made. An experimental approach for reducing costs of the latter was proposed.

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WATER QUALITY EFFECTS RELATED TO BLENDING WATERS IN DISTRIBUTION SYSTEMS

by

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Grant No. R804709

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This study evaluates the effects of blending two or more waters of different quality and relates their composition to the corrosive effects of the water in distribution systems. The EPA's mobile water quality monitoring laboratory was used to amass field data on parameters related to corrosivity and stability of waters representing those available in Southern California. The study should provide a data base to support the states and EPA in their responsibilities under the Safe Drinking Water Act to determine the need for water quality control programs to minimize health effects associated with the presence of contaminants that are the products of corrosion in water distribution systems.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This study was conducted to evaluate the effects of blending two or more waters of different quality and to relate their composition to the corrosive effects and calcium carbonate deposition tendency of the water on distribution systems. The EPA mobile water quality monitoring laboratory was deployed at 30 selected sites within the service area of The Metropolitan Water District of Southern California where imported waters from the Colorado River and California aqueducts are used as delivered or blended with local groundwaters. Eighteen computer controlled parametric systems on board the laboratory analyzed and recorded field data to assess water quality factors associated with corrosion and stability. The waters studied could be classified as having moderate to high hardness, alkalinity and total dissolved solids content.

The data were analyzed for significant interrelationships relative to pH, calcium hardness, alkalinity, dissolved minerals, polarization corrosion rates on day 7, calcium carbonate deposition test (CCDT) results, and calculated values for the Langelier saturation index and Ryzner stability index.

For waters of similar chemical composition the CCDT results were more indicative of the benefits to be derived from pH control or zinc phosphate films for mitigating corrosion than the polarization corrosion rates.

Cost comparisons for corrosion control by use of caustic soda to adjust pH and zinc phosphate to promote protective film deposition were made. An experimental program of intermittent application of zinc phosphate was proposed to optimize the costs and benefits of this treatment.

The continuous monitoring systems have the capability of responding to those differences in water quality which can then be used to make qualitative comparisons of the relative stability and/or corrosivity of waters blended in distribution systems.

This report was submitted in fulfillment of Grant No. R804709 by The Metropolitan Water District of Southern California, Los Angeles, California under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from October 1976 to October 1978.

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables ix
Acknowledgment x

1. Introduction 1
  General 1
  Objectives and Study Plan 4

2. Conclusions 6

3. Recommendations 9

4. The EPA Mobile Water Quality Monitoring Laboratory 11
  General 11
  Improvements to the Mobile Laboratory 15
    Dual Power Hook-Up Capability 15
    Air-Conditioning and Temperature Control 15
    Modifications to Existing Monitoring Systems 17
      Schneider Robot Monitor 17
      Residual Chlorine Analyzers 17
      Calcium Carbonate Deposition Test 17
      Corrosion Rate Meter 18
      24-Bottler Sampler 18
    Monitoring Equipment Added by MWD 20
      H-F Turbidimeter 20
      Turbine Flowmeter 20
  Mobile Laboratory Computer System 21
    General 21
    Worker Tasks 21
    The DAQ Worker Task 22
    Computer Cooling Problems 27

5. Data Handling and Presentation 28
  Paper Tape Data 28
  Recorder Chart Data 29
  Data Processing 29

CONTENTS (continued)

6. Experimental Field Monitoring 34
  Monitoring Sites 34
    Site Operating Conditions 34
  Parameters Monitored 41
  Sampling for Manual and Special Analysis 41
  Monitoring Period 43
  Cleaning Corrosion Electrodes 43
  Cleaning CCDT Electrodes 43
  Special Attention for the CCDT 44
  Instrument Calibration 44
  Instrument Problems 44

7. Results and Discussion 47
  General 47
  Interrelations Between Water Quality Parameters 59
    Effect of pH on Corrosion Rates 59
    Effect of Calcium Content on Corrosion Rates 61
    Effect of Dissolved Minerals on Corrosion Rates 61
  Calcium Carbonate Deposition Test (CCDT) 65
    Effect of pH Adjustment on CCDT 67
    Effect of Alkalinity and Hardness on CCDT 67
    Effect of Zinc Phosphate on CCDT and Corrosion Rates . . 67
  Corrosion Coupon Tests 75
  Interrelations between CCDT and Other Quality Paremeters . 76
  Response of Monitoring Systems to Quality Changes 81
  Cost of Corrosion Control Treatment 84

References 86
Appendix 88

FIGURES

Number Page

1 MWD distribution system and service area 2

2 Aqueducts serving Southern California 3

3 Photographs of EPA Mobile Water Quality Monitoring Laboratory--a) Exterior; b) Interior 12, 13

4 Electrical service disconnect box 16

5 Schematic diagram of corrosion monitor flow cells with constant-head flow regulation 19

6 Schematic diagram of CCDT automation relay control panel 26

7 Computer-plotted water quality data at Locations 25 -- Graph A . 32

8 Computer-plotted water quality data at Locations 25 -- Graph B . 33

9 MWD system delivery pattern showing monitoring locations-- Pre-drought period (before March 1977) 35

10 MWD system delivery pattern showing monitoring locations-- Drought period (March 1977-February 1978) 36

11 MWD system delivery pattern showing monitoring locations-- Post-drought period (after March 1978) 37

12 Corrosion rates for mild steel, zinc, and copper on day 7 vs. Langelier saturation index 60

13 Corrosion rates for mild steel, zinc, and copper on day 7 vs. Ryzner stability index 62

14 Corrosion rates for mild steel, zinc, and copper on day 7 vs. calcium content 63

15 Corrosion rates for mild steel, zinc, and copper on day 7 vs. electrical conductivity 64

16 Effect of blending Colorado River water and State Project water on CCDT 66

FIGURES (continued)

Number Page

17 Effect of pH adjustment of blended waters on CCDT 68

18 Effect on CCDT due to in-line diurnal changes in source of water at Location 29 69

19 Effect of adding zinc phosphate for corrosion control on CCDT 71

20 Photographs of corrosion electrodes at (a) Location 13 and (b) Location 28 74

21 CCDT results vs. calcium and alkalinity levels 77

22 CCDT results vs. corrosion rates for mild steel and zinc on day 7 78

23 CCDT results vs. Langelier and Ryzner indices 79

24 Data showing diurnal variations in water quality at Location 29 -- Graph A 82

25 Data showing diurnal variations in water quality at Location 29 -- Graph B 83

A-1 Flowchart of DAQ (MWD modification No. 3) 91

A-2 Flowchart of DAQ Subroutine A 92

A-3 Flowchart of DATA (MWD modification) 92

A-4 Flowchart of PUN 93

TABLES

Number Page

1 Sensors in the EPA Water Quality Monitoring Laboratory 14

2 Mobile Laboratory Field Monitoring Locations 38

3 Parameters Monitored for MWD Mobile Laboratory Project 42

4 Chemical Analysis of MWD Source Waters--Averages from January 1977-June 1978 48

5 Typical Chemical Analysis of MWD Filtered Waters--Monthly Composite of Daily Samples 49

6 Typical Chemical Analysis of Groundwaters Used During Study 50

7 Summary of Water Quality Data for Field Monitoring Stations . . 51

8 Corrosion Rates for Mild Steel, Zinc, and Copper from Field Monitoring Stations 52

9 Comparison of Long Term Corrosion Tests--Mild Steel 55

10 Comparison of Long Term Corrosion Tests--Zinc 56

11 Comparison of Long Term Corrosion Tests--Copper 57

12 Trace Metal Levels at Field Monitoring Stations 58

13 Comparisons of Corrosion Rates for Waters With and Without Zinc Added for Corrosion Control 70

14 Zinc Levels for Locations Where Zinc Corrosion Inhibitor was Added 72

15 Iron in Long Beach Distribution Water 75

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SECTION 1

INTRODUCTION

GENERAL

Regional water systems designed for the efficient collection, treatment, and distribution of water in large urban areas have been remarkably successful in meeting the needs of the large population served. Inherent in most regional plans is the right of water purveyors within the regional boundaries to retain and utilize their historical water sources. Moreover, due to the higher cost of imported water, the local supply is often used exclusively part of the year and supplemental water from the regional system is purchased as needed during periods of peak demand. Thus, in an area with a regional supplemental water supply there is the chance that a given distribution system may be exposed to two waters of different quality and origin and to various blends of the two waters. With daily, weekly, monthly, or seasonal changes in water quality, there is the possibility that these changes could have an adverse effect on the distribution system itself or on the quality of the water delivered to the consumer.

The Metropolitan Water District of Southern California (MWD) operates one such regional water distribution system. MWD is a public and municipal corporation of the State of California which provides supplemental water, as a wholesaler, through its 27 member agencies (cities and water districts) to nearly 11 million people in a 4900-square-mile service area on the coastal plain of Southern California, as shown in Figure 1. MWD imports water to Southern California from two distant sources; the Colorado River via the Colorado River Aqueduct, and the Sacramento-San Joaquin Delta in Northern California via the California Aqueduct, see Figure 2. Approximately one-half of this supplemental water--700,000 acre-feet--is being imported annually from the Colorado River. Initial deliveries of Colorado River water (CRW) began in 1941. In addition, Metropolitan has contracted to ultimately receive more than 2 million acre-feet annually of Northern California water through the State Water Project (SWP). First deliveries of northern water began in 1972.

There are 128 incorporated cities within Metropolitan's boundaries and the imported water comprises from 0 to 100 percent of the water delivered to the consumers in various cities. MWD supplies three different waters, either treated or raw, to its member agencies; Colorado River water (CRW), State project water (SPW), and a blend of Colorado River and State project waters (CRW/SPW). Most of the communities within Metropolitan's service area have some local groundwater supply of their own that is used

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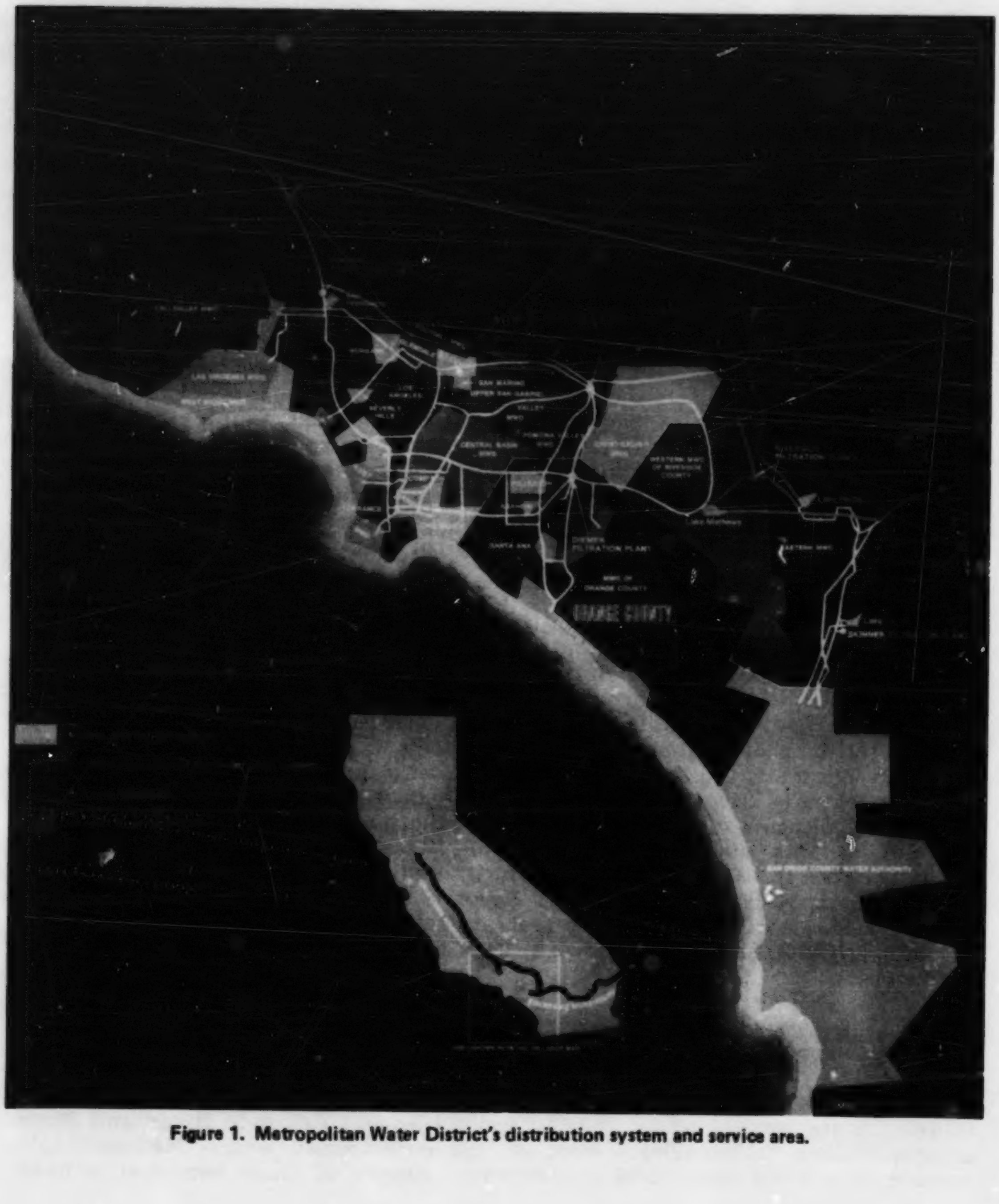
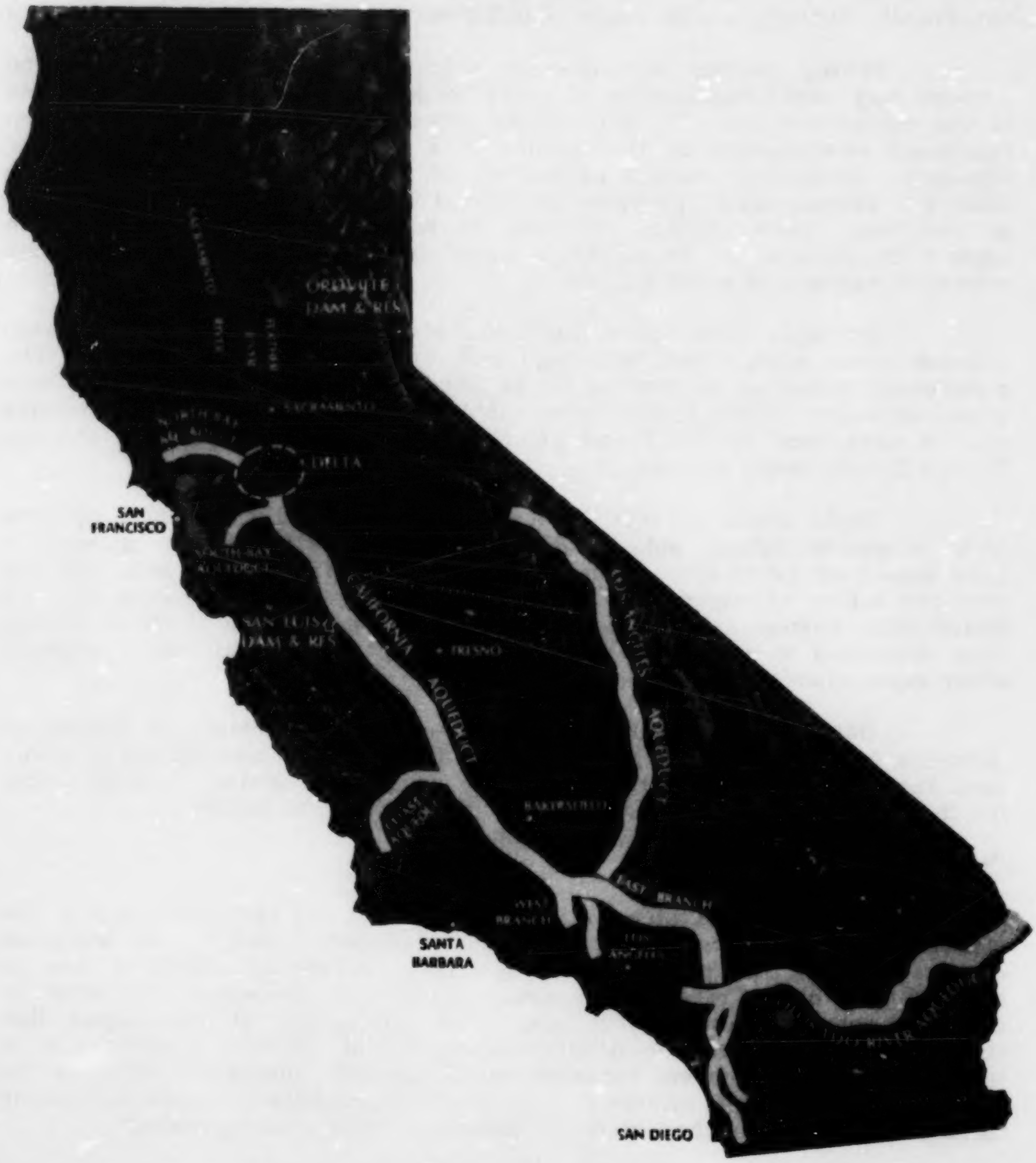

LAS VIRGENES MWD
LOS ANGELES
SAN MARINO
UPPER SAN GABRIEL
BEVERLY HILLS
VALLEY MWD
POMONA VALLEY MWD
CENTRAL BASIN MWD
WESTERN MWD OF RIVERSIDE COUNTY
SANTA ANA
DIEMER FILTRATION PLANT
Lake Mathews
MWD OF ORANGE COUNTY
ORANGE COUNTY
SAN DIEGO COUNTY WATER AUTHORITY

Figure 1. Metropolitan Water District's distribution system and service area.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SACRAMENTO
DELTA
SAN FRANCISCO
SOUTH BAY AQUEDUCT
SAN LUIS DAM & RES
FRESNO
CALIFORNIA AQUEDUCT
LOS ANGELES AQUEDUCT
COASTAL AQUEDUCT
BAKERSFIELD
EAST BRANCH
WEST BRANCH
SANTA BARBARA
LOS ANGELES
COLORADO RIVER AQUEDUCT
SAN DIEGO

Figure 2. Aqueducts serving Southern California

intermittently or blended more or less continuously with this imported water. Each local supply may vary significantly from a quality standpoint. Thus, within the confines of Metropolitan's service area there is a good opportunity to study a wide range of different water blends.

Mixing waters of different origin and quality in distribution systems may cause the quality of water to deteriorate before it is delivered at the consumer's tap. To date, there have been few attempts to establish functional relationships in the quality of a water supply before and after blending. Monitoring various parameters of water quality should provide a basis for assessment of problems associated with corrosion and stability due to blending. Such studies will help in developing a plan for corrosion control in addition to providing a basis for establishing consumer costs related to changes in water quality.

Attempts have been made to establish a functional relationship between water quality and household cost by interviewing consumers. The parameters measured in these surveys have generally been related to total dissolved solids (TDS) and/or hardness of waters. The most comprehensive studies were done by Black and Veatch (1), Metcalf and Eddy (2), and the Orange County Water District (3).

While these surveys have done much to point out the long-term costs of poorer quality water, they have done little to provide answers to more immediate problems. Among these are the effects of periodic shifting from one source of water to another or of blending different waters within a distribution system rather than at a central point. Some of these factors were discussed in a paper by Pearson and Singer (4) for the major regional water importation system operated by MWD.

Detailed investigation of water quality parameters is needed to delineate factors related to corrosivity and stability of blended water within such regional systems in order to develop adequate treatment methods either for the local water supplier or for the regional system to employ.

Objectives and Study Plan

The principal objective of this project was the evaluation of the effects of blending two or more waters of different origin and inorganic chemical content in public water systems. A second objective was to quantify corrosion rates and calcium carbonate deposition tendency in dynamic water systems before and after blending. It was hoped that control measures could be developed that would minimize deterioration of water distribution system facilities and household plumbing. Methods for mitigating unfavorable effects due to unstable conditions caused by mixing different waters could then be recommended to water utility managers.

In October 1976, MWD was awarded a shared cost research grant from the Environmental Protection Agency (EPA) to use their mobile water quality monitoring laboratory designed and assembled by the National Sanitation Foundation (5) to study the effects on water quality due to blending waters of different origin. As indicated above, the area of

Southern California served by MWD is an especially good area to study changes in water quality due to blending because of the variety of waters and blends of waters used in the various Southern California communities.

MWD has three 400 mgd and one 150 mgd filtration plants which provide water for domestic purposes in Los Angeles, Orange, San Diego and Ventura Counties. The effluent from each of MWD's plants is stabilized by final pH adjustment, but the treated waters are later commingled with local groundwaters which may vary in mineralization from 200 to 750 mg/L of TDS and some contain significant amounts of free carbon dioxide. Monitoring locations for this project were selected to obtain data for making comparisons of the corrosivity and stability of MWD's two waters, Colorado River Water (CRW), and State project water (SPW), blends of the two (CRW/SPW), and blends of these waters with local water.

Several communities in the Southern California area add zinc phosphate corrosion inhibitors to their water supplies. Monitoring of water quality in these systems above and below the point of adding zinc phosphate was included in the study plan to provide insight into the value of such treatment.

An important corollary objective of this investigation was to accumulate a data base related to corrosivity and stability parameters to be made available to the states and EPA for support of their responsibilities under the federal Safe Drinking Water Act (SDWA). As amended in November 1977, the SDWA authorizes EPA to prescribe special monitoring requirements for unregulated contaminants. Such monitoring may provide criteria for water quality control to minimize health effects associated with the presence of contaminants, including metals (e.g. lead and cadmium) that are products of corrosion in the distribution system.

When the EPA published proposed amendments to the National Interim Primary Drinking Water Regulations on July 19, 1979 (6), comments were solicited on the applicability and limitations of several corrosivity and stability indices to assess whether a particular water is corrosive. The monitoring of water quality parameters on-board the mobile laboratory was designed to procure data for evaluation of such indices for the types of water sources within the study area.

SECTION 2

CONCLUSIONS

1. The EPA mobile water quality monitoring laboratory was an effective tool for concurrently collecting data on a broad spectrum of water quality parameters. Most certainly the quantity of data collected could not have been possible without the continuous monitoring systems and the on-board minicomputer. Such a capability is very helpful in defining the characteristics of the distribution system with respect to both water quality and diurnal flow patterns.

2. During the course of this project, which was the first extensive investigation employing the EPA mobile laboratory, a number of improvements and/or modifications were made on the monitoring systems. These changes were made in order to either overcome problems experienced in actual use of the laboratory or to save time both in servicing the instruments and in analyzing the data. The modifications were:

(a) Adding zinc and copper sensors to the corrosion rate monitoring system. A constant head flow control was also added to maintain a uniform flow in the corrosion cells.

(b) Automating the calcium carbonate deposition test (CCDT) to allow for continuous collection of data.

(c) Adding a turbine flow meter which was then used to regulate the total water flow into the laboratory.

(d) Reprogramming the computer's data acquisition worker task to record additional parameters by the computer. The program modification also allowed for greater flexibility in changing the time sequence for data collection.

3. The waters studied at 30 field locations on this project could be classified as having moderate to high hardness, alkalinity and total dissolved solids content. In general, the pH was near the saturation value and free carbon dioxide was low to moderate. Attempts were made to establish interrelations between the several water quality parameters measured, calculated saturation and corrosion indices, and the results of intantaneous polarization corrosion rate measurements on day 7. For the waters investigated the following relations were observed:

(a) Corrosion rates for mild steel and zinc decreased moderately as the Langelier saturation index shifted from negative to positive.

(b) A slight trend toward higher corrosion rates for mild steel and zinc was noted as the Ryzner index increased from 6.9 to 8.8.

(c) There was a slight trend toward lower corrosion rates for zinc as the calcium content increased.

(d) No observable trend toward higher corrosion rates for mild steel and zinc were noted as the conductivity of the waters increased. A slight trend toward higher corrosion rates for copper was noted at higher conductivities.

(e) The more complex problem of galvanic corrosion could not be studied by the polarization corrosion rate meter on board the mobile laboratory.

4. The calcium carbonate deposition test proved to be one of the most sensitive tests performed by the mobile laboratory. It responded immediately to changes in water quality; however, the significance of this response was not always evident. When the two MWD water sources were blended in varying ratios, there was a progressive delay in the onset of film formation as the calcium hardness in the blend decreased. Once the film began to form the CCDT slopes were not markedly different. Diurnal changes in water quality due to in-line mixing of groundwater with the MWD water which caused marked increases in alkalinity and/or calcium hardness were readily detected by the CCDT meter.

5. The CCDT meter appears to provide evidence of the formation of porous or discontinuous films deposited on the rotating gold sensor. In some cases the microcurrent flow did not drop to zero on long exposure to the water. In another, the current flow increased after a water of lower alkalinity reached the laboratory. We believe this indicates partial dissolution of the original film to satisfy new equilibrium conditions. Such information is of value for assessing the impact of water quality changes on the stability of pipeline deposits.

6. Interrelations between the CCDT data and other water quality data were explored. For the waters not treated with zinc phosphate in this investigation, the following relations were observed:

(a) Because of the scatter of points, there was no firm evidence of an inverse relation between the polarization corrosion rate for mild steel and CCDT values.

(b) A moderate inverse trend was noted between zinc corrosion rates and CCDT values.

(c) A strong positive trend toward higher CCDT values was observed as the calcium content and alkalinity of the waters increased.

(d) There was only slight evidence of a direct relation between the CCDT values and the Langelier saturation index. We believe this is because all of the waters studied contain moderate to high levels of bicarbonates and calcium hardness.

(e) Lower CCDT values were associated with higher values for the Ryzner index. This should be expected since the higher Ryzner index indicates an increase in the calcium carbonate dissolving tendency, the opposite of the CCDT representing a deposition rate.

7. The addition of zinc orthophosphate as a corrosion inhibitor in three of the water systems monitored during this project caused the most rapid film formation rate to be recorded by the CCDT meter. There was, however, no consistent evidence of an improvement in the day 7 corrosion rates measured of the polarization method in the mobile laboratory. Corrosion coupon tests performed by others were not always supportive of the need for adding this chemical to these waters. However, such application appears to be most beneficial to bridge a transition period when shifting from well water to imported surface water. Because of the ambivalence concerning the beneficial effects of this treatment and its cost effectiveness, recommendations for studying the possibility of intermittent feeding of the orthophosphate have been made.

8. In one case, the diurnal shifting from one water source to another resulted in higher corrosion rates during the period when the surface water was blended with the well water than when either water was delivered alone. The continuous monitoring systems on the mobile laboratory provide a means for diagnosing problems which may evolve from this type of operation. The data would represent qualitatively a directional tendency toward more or less calcium carbonate film formation and higher or lower corrosion rates, but the data would not quantify these differences. Possibly by the use of weight-loss coupon test methods in conjunction with the laboratory tests, quantification of the magnitude of these effects could be achieved.

9. On the basis of this study, the blending of imported surface waters and their mixing with local groundwaters in the southern California communities served by The Metropolitan Water District of Southern California has not generated serious water quality problems in the distributions systems of the area.

SECTION 3

RECOMMENDATIONS

1. The EPA mobile laboratory should be deployed in several communities across the country where each is serving water representing one of the many types of water being used in public water supplies. The laboratory could then provide a data base for evaluating those parameters needed for determining the stability or corrosiveness of waters. Since no single parameter seems to be reliable for assessing these quality characteristics, a combination of well-defined parameters might be selected on the basis of concurrent measurements taken on-board the mobile laboratory.

2. For systems where water quality changes due to blending, mixing or storage result in water quality deterioration, the mobile laboratory is an excellent diagnostic tool. It can be used to identify changes and to study the efficacy of modifying operations, including treatment, to improve water quality.

3. When the mobile laboratory is to be used for investigating corrosion rates, a protocol should be adopted to place a set of mild steel, zinc, and copper electrodes for advance exposure to the water to be tested some three or four weeks before the laboratory will arrive at this location. The water being tested should flow continuously through the cells at predetermined velocities during this conditioning period. A second set of freshly cleaned electrodes should be installed in a flow cell on-board the laboratory, and corrosion rate measurements made on each set will provide comparative data for immediate and long-term passivated electrodes, the latter approaching equilibrium corrosion rate measurements. This would require modifying the corrosion rate meter to handle more than the four stations presently available in the instrument.

4. Further study is needed to determine factors related to the reported effectiveness of zinc phosphate as a corrosion inhibitor. The possibility of intermittant feeding of the chemical to a previously zinc phosphate passivated system should be investigated as a means of making the process more cost effective.

5. The mobile laboratory with its 18 integrated, computer-controlled, parametric systems should be used as a research tool rather than for routine surveillance activities. This recommendation is based on the rather rigorous siting requirements to provide sufficient water, power, and water disposal facilities for proper laboratory operation. The time required for setting up and recalibration of the instruments at each new location mitigate against brief stops.

6. Depending on the objectives of the research project, some of the more sophisticated monitoring systems may not be required as in the current project. We believe that to operate the laboratory at its designed monitoring capacity, two chemists familiar with all the chemical instrumentation on-board are needed and that one or both chemist operators should be familiar with electronics and the operation of minicomputers.

SECTION 4

THE EPA MOBILE WATER QUALITY MONITORING LABORATORY

GENERAL

The EPA mobile water quality monitoring laboratory was designed, assembled, and initially tested by the National Sanitation Foundation (NSF) in Ann Arbor under a contract from the EPA, "Water Quality Monitoring in Distribution Systems." (5) Exterior and interior photographs of the laboratory are shown in Figures 3a and 3b, respectively. It was the purpose of the EPA funded project to develop and test a variety of automated analytical techniques which could be used to detect and measure changes in quality which may occur in potable water during transmission through distribution systems.

The NSF had developed for the EPA a prototype mobile laboratory for monitoring drinking water quality with 18 integrated, computer-controlled, parametric systems installed in the mobile laboratory. The 18 sensor systems as developed by the NSF and in some cases modified by the EPA Research Center in Cincinnati, Ohio, are listed in Table 1. The calcium system was added by the EPA (7). The monitoring systems as well as the complete mobile laboratory are described in detail in the NSF project report (5).

MWD received the EPA mobile laboratory in October 1976. The unit was shipped to MWD from EPA's Water Supply Research Center in Cincinnati, Ohio, lashed onto a lowboy trailer. On arrival at MWD's Central Laboratory in La Verne, California, a number of nuts and bolts had separated and several soldered connections in the monitoring equipment had broken as a result of road vibrations during shipping. Considerable time was spent locating the problems and making the necessary repairs.

After observing the problems caused during transportation to California, it was decided to install some additional cushioning on several of the mounted instruments. While working with the laboratory for several weeks during the initial training and learning period, it became obvious that if the laboratory were going to be moved often, some modification needed to be made that would shorten the setup and takedown times. A number of modifications were made to instruments which were normally shipped and stored in boxes and had not been permanently mounted. As much as feasible, these instruments were permanently mounted with cushioning to available counter and wall space.

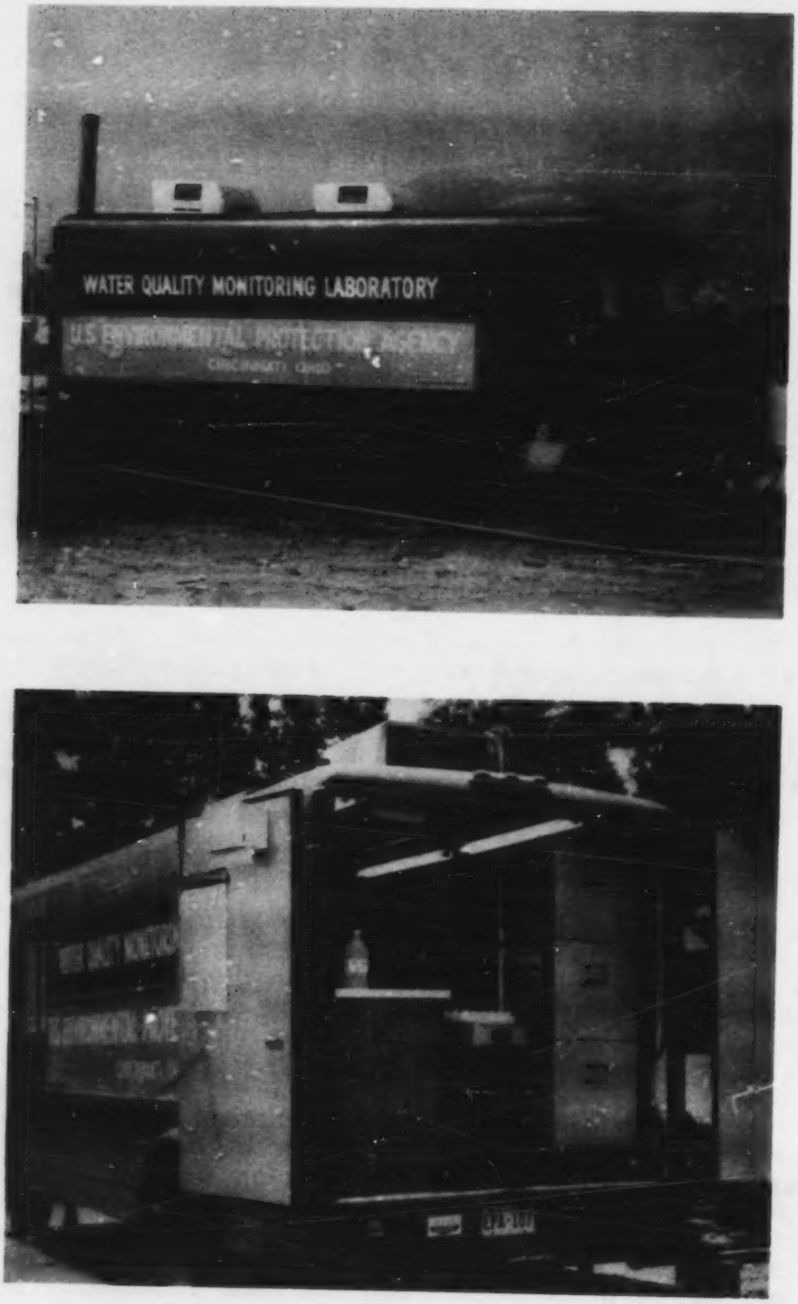

WATER QUALITY MONITORING LABORATORY
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI OHIO

Figure 3a. Exterior photographs of the EPA mobile water quality monitoring laboratory.

Figure 3b. Interior photographs of the EPA mobile water quality monitoring laboratory.

TABLE 1. SENSORS IN THE E.P.A. WATER QUALITY MONITORING LABORATORY WHEN RECEIVED

Parameter	Sensor Type	Unmodified Commercially Available System
Temperature	Thermistor	x
Conductivity	A-C Conductivity Cell	x
pH	Glass Electrode	x
Chloride	Solid State Ion-Selective Electrode	x
Dissolved Oxygen	Voltammetric Electrode	x
Free Residual Chlorine	Galvanic Cell	x
Total Residual Chlorine	Galvanic Cell	x
Turbidity	Nephelometer	x
Corrosion Rate	Polarization Admittance Technique	x
Free Fluoride	Solid State Ion-Selective Electrode	
Total Fluoride	Solid State Ion-Selective Electrode	
Alkalinity	Potentiometric Combination-pH Electrode	
Hardness	Liquid Junction Ion-Selective Electrode	
Nitrate	Liquid Junction Ion-Selective Electrode	
Calcium	Liquid Junction Ion-Selective Electrode	
Cadmium	Differential Anodic Stripping Voltammetry (DASV)	
Lead	DASV	
Copper	DASV	
Calcium Carbonate Deposition Test	Potentiostatic Rotating Ring Disc Electrode	

During the initial training and learning period considerable time was spent attempting to get the ion-selective electrode monitoring systems to operate correctly (Ca^{++}, Hardness, NO_3^-, free F^-, total F^-, alkalinity). There were continual problems in obtaining good data because of troubles with the sampling and recording systems. It became obvious that the effort expended in relation to the reliability of the information obtained was not justified. Too much time was needed for operating these systems and the resultant data was not completely reliable. Thus, it was decided not to operate these systems and to perform manual titrations for calcium, hardness, and alkalinity using samples taken by the 24-bottle sampler. Nitrate and the fluoride species were not monitored because these species were not considered to be of prime importance for the purposes of the study. Using the data acquisition regime for the ion-selective electrode systems as controlled by the computer, one analysis value was obtained every 22 minutes. Using the 24-bottler sampler, a sample can be taken every hour. This sampling regime gives fewer data points; however, it was felt that the effort put into obtaining the data and the reliability of the data were in a more nearly optimal ratio.

The anodic stripping voltammetry (ASV) system for trace metal analysis was not used during this study for two reasons. Firstly, the ASV system was not functional when the mobile laboratory was received by MWD. The ASV unit in the laboratory was a newly designed instrument that had not been thoroughly tested or used. Secondly, most of the distribution system piping in the areas where the water was monitored was made of materials that would not add significant amounts of the ASV detectable trace metals: lead, cadmium, and copper. Samples for trace metals were taken periodically at each location and analyzed by atomic absorption spectroscopy.

IMPROVEMENTS TO THE MOBILE LABORATORY

Dual Power Hook-Up Capability

The mobile laboratory was initially designed to be operated using a 240/220-volt 20-amp electrical service. The electricity was supplied to the mobile laboratory by a cable attached to an appropriate electrical source. In selecting field monitoring sites for the mobile laboratory, it was determined that a number of the sites chosen did not have the needed 240-volt electrical service, but rather a 480-volt supply. A 10-kVA 480-to-240-volt transformer was installed on board the laboratory. A special disconnect box, Figure 4, was also installed which was set up so that either a 480-volt or a 240-volt supply could be used as the electrical service for the mobile laboratory, depending on which way the lever was thrown. Each of the two voltage supplies has a different type of cable connector attached to pigtail cables from the disconnect box. This was done to eliminate possible confusion regarding which voltage is connected to which input cable.

Air Conditioning and Temperature Control

The mobile laboratory was initially designed with one 12,000 BTU roof mounted air-conditioner. During days when the mobile laboratory was

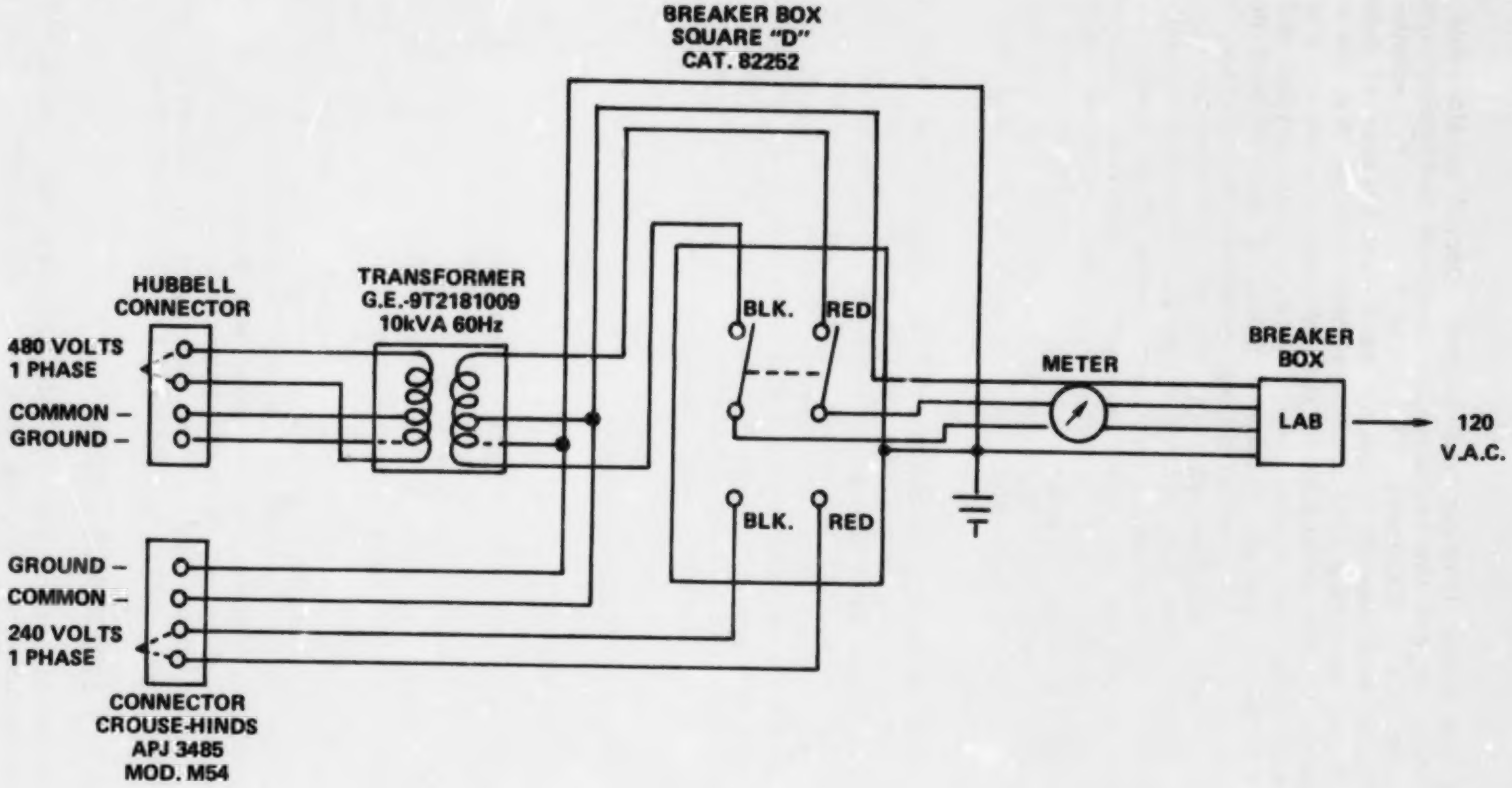

BREAKER BOX
SQUARE "D"
CAT. 82252
HUBBELL CONNECTOR
TRANSFORMER
G.E.-9T2181009
10kVA 60Hz
480 VOLTS 1 PHASE
COMMON –
GROUND –
BLK.
RED
BLK.
RED
METER
BREAKER BOX
LAB
120 V.A.C.
GROUND –
COMMON –
240 VOLTS 1 PHASE
CONNECTOR
CROUSE-HINDS
APJ 3485
MOD. M54

Figure 4. Electrical Service Disconnect Box.

sitting in a sunny location, the temperature inside the laboratory would commonly reach 85°-95° F, even with the air-conditioner on maximum cool. Even though the mobile laboratory is relatively small, the dark blue exterior absorbs great amounts of heat from the sun. Added to this is a considerable amount of heat from the instruments and computer. Not only was this extremely uncomfortable for the operators, it was a potentially serious hazard to the computer. On hot days the temperature on top of the central processing unit would climb to 115°-120° F. The computer manufacturer recommends 72° F as the optimum operating temperature for the computer. To remedy overheating situations, a second roof-mounted air-conditioner was installed (Duotherm 13,500 BTU).

The large amount of window space in the front of the mobile laboratory admits heat from the sun which is further intensified by the greenhouse effect. Cardboard inserts painted white were made and used to cover each window thereby eliminating this source of heat. These covers were either set in place or held over the windows with tape and could be easily installed and removed when changing locations. In addition to reducing heat due to sun, these window coverings added to the security of the laboratory. It was almost impossible to see into the laboratory when they were in place, and the amount and kinds of equipment contained inside were not revealed.

Modifications to Existing Monitoring Systems

Schneider Robot Monitor --

Cup inserts were made that could be filled with water and placed into the monitor's flow cells. This way the electrodes could be kept in water during transit, eliminating problems that might occur as a result of the electrode sensors drying out.

Residual Chlorine Analyzers--

The pump used to supply standard chlorine solutions when calibrating the residual chlorine analyzers was permanently mounted to the outside base of the Schneider Robot Monitor (SRM). In addition, polyethylene tubing was installed permanently from the pump to the input line to the chlorine analyzers. A shutoff valve at this point allowed for a choice of either the standard solution or the tap water to be analyzed.

Calcium Carbonate Deposition Test --

The calcium carbonate deposition test (CCDT) rotator and potentiostat were permanently mounted to available bench and shelf space respectively, on the left side (as facing forward) of the laboratory. These units had not been previously mounted, which would have necessitated boxing the instruments for each move. The CCDT system when received was a completely manual operation, that is, the test had to be started and stopped manually. The data, which was recorded on a strip chart, had to be manually transposed to tabular form so that data cards could be punched. The data from the cards were then merged with the data from the on-board computer so that all the laboratory analysis data could be in computer storage. A modification was made in the data acquisition program of the on-board computer that allowed for the computer to record the CCDT data. This modification was started with Location 6. Near the end of the project the complete CCDT analysis cycle was automated with computer control. A more complete description of the computer modifications and data handling will follow in subsequent sections of this report.

Corrosion Rate Meter --

The mobile laboratory came equipped with a Petrolite four-station corrosion rate meter (CRM); however, no provision had been made for flow cells in which to place the electrodes which measure the corrosion rate. Thus, before any field monitoring was started flow cells, shown in Figure 5, had to be constructed and proper cables, electrodes, and electrode holders had to be purchased from Petrolite. A rack to accomodate three flow cell chambers was made; one cell held the original mild steel electrodes supplied with the laboratory while the other two cells were added to house sets of zinc and copper electrodes. A special rack for securely holding the CRM was constructed and mounted in unused space under the bench on the right side of the laboratory. The unit is easily removed from the rack for necessary access and servicing.

Initially, the flow to the electrode cells was set by adjusting the small globe valve on the water source line, and maintenance of flow was attempted using visual observation of the output overflow from the flow cells. After some time it was observed that this type of flow adjustment was quite inaccurate and that the flow to the cells varied daily due to changes in the source line flow and pressure and poor flow control by the globe valve. A flow meter was installed in the feed line to the corrosion cells and the total flow set at 0.5 L/min for the three cells. Observing the flow meter over a period of several days confirmed the fact that the flow changed periodically. Several constant-flow restriction valves were tried, but with no success.

It also appeared that the corrosion rate measurements were flow dependent and needed a better and more accurate flow regulation system. A constant-head flow regulation device was designed, which had an adjustable head level that could be used to adjust the flow (Figure 5). This was installed and initially put in service at sampling Location 13. The constant-head device for maintaining a constant flow proved to be very satisfactory.

24-Bottle Sampler--

The 24-bottle sampler (Sigmamotor) supplied with the mobile laboratory was designed to take a sample only upon a signal from some external source. Originally this external source was the computer. There was a separate worker task program written for the computer that was supposed to activate the sampler every hour so that it would take a sample. However, there was no documentation information available on exactly how to operate the computer so that it would take the sample. Periodically the computer would activate the sampler, but the time interval between samples was not always consistent and sometimes there would be no samples taken for a whole day. The sampler could not be used in this manner and an alternative had to be found. The sampler was taken off computer control and connected to a 24-hour timer with adjustable event control (Paragon Model 25001-OS Program Time Switch). The new timer can be set to take

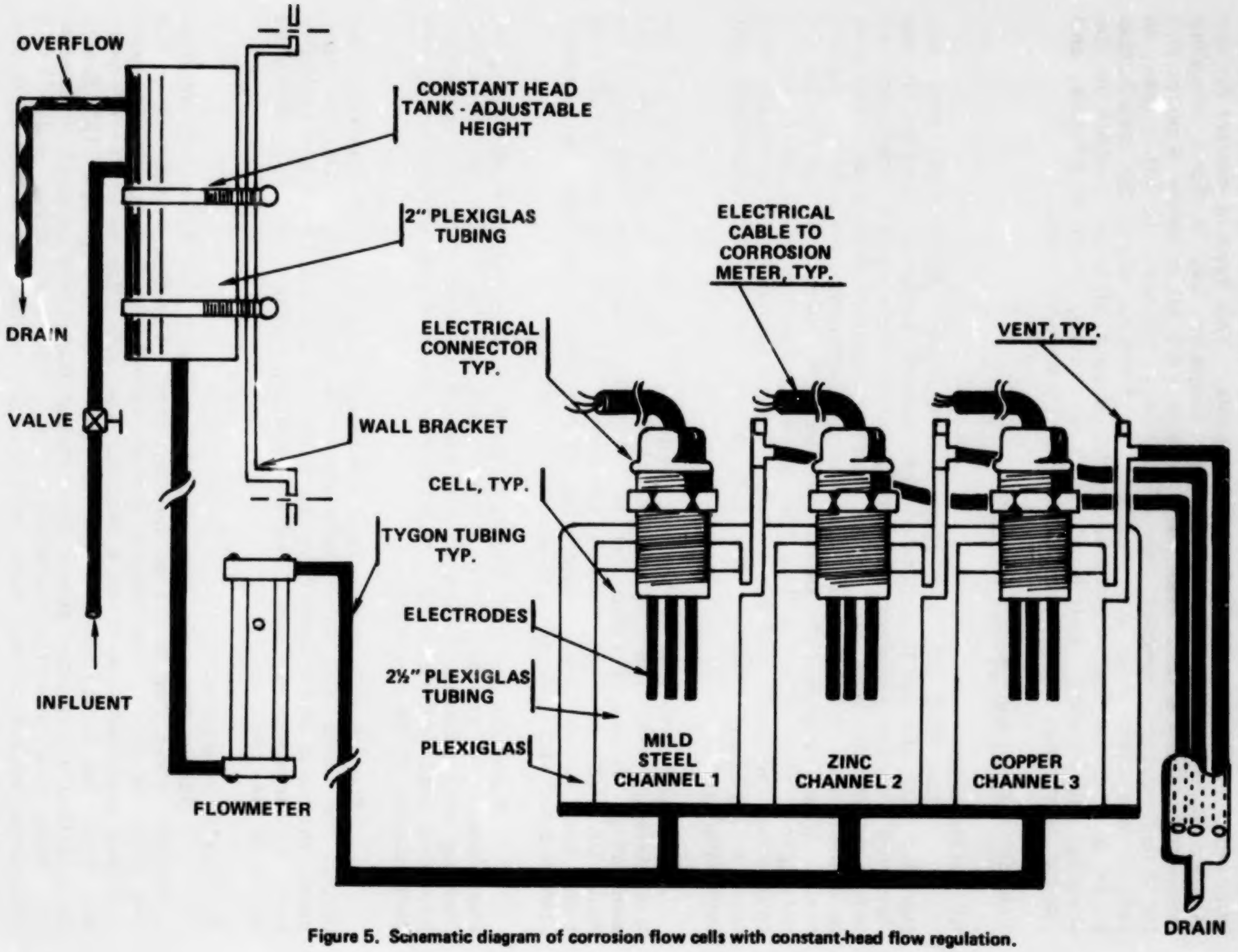

OVERFLOW
CONSTANT HEAD TANK - ADJUSTABLE HEIGHT
2" PLEXIGLAS TUBING
DRAIN
VALVE
INFLUENT
ELECTRICAL CABLE TO CORROSION METER, TYP.
ELECTRICAL CONNECTOR TYP.
VENT, TYP.
WALL BRACKET
CELL, TYP.
TYGON TUBING TYP.
ELECTRODES
2½" PLEXIGLAS TUBING
PLEXIGLAS
MILD STEEL CHANNEL 1
ZINC CHANNEL 2
COPPER CHANNEL 3
FLOWMETER
DRAIN

Figure 5. Schematic diagram of corrosion flow cells with constant-head flow regulation.

samples every hour or in any desired sequence with 5-minute minimum intervals. It has proved to be very reliable. This type of control for the sampler is very versatile, while the computer had a fixed sampling frequency. Over normal weekends, samples were taken every 3 hours and for 3-day weekends samples were taken every 4 hours. In either case, 24 samples are taken over the weekend. At locations where the distribution water is a blend and the blend varies during high-use periods in the morning and evening, samples can be taken every 15 or 30 minutes, and during other hours samples can be taken every several hours.

Monitoring Equipment Added By MWD

HF Turbidimeter--

The Hach CR low range turbidimeter, Model 1720, that was supplied with the mobile laboratory had several problems. Firstly, it was observed that the calibration procedure, using the standard reflectance rod supplied with the unit, was not an adequate means of calibration. The unit is calibrated on the 0-5 scale while the measurements are made on the 0-1 scale. When samples were taken into the main laboratory, the results did not agree, even after calibration. It was found that the best way of calibrating the Hach unit was to take a sample into the main laboratory and take a turbidity reading, and then adjust the mobile laboratory unit accordingly.

This means of calibrating worked well when the mobile laboratory was stationed near the central laboratory, but was impractical when field monitoring. It was therefore decided to install a second turbidimeter, a HF Model DRT 200, into the mobile laboratory. This unit has the flexibility of being used for continuous monitoring or for discrete samples, and is easily standardized with a standard reference solution vial.

Since the HF unit had the capability of continuous monitoring, it was decided to record turbidity from both the Hach and the HF units. Starting with Location 7, the HF turbidity was recorded on the computer. Recorded data from the two turbidimeters allows for a comparison of the performances of the two units.

The HF unit has another advantage over the Hach--the scale and output are linear and thus easily converted to turbidity. On the other hand, the scale and output from the Hach unit are non-linear and turbidity must be interpolated from a table (turbidity units (TU) vs. millivolts) stored in the computer.

Turbine Flowmeter--

During the early stages of the project it was difficult to maintain a constant water flow to the mobile laboratory. The flow would vary as the line pressure in the distribution system varied. A flow regulating valve that was supposed to maintain a constant flow with changes in line pressure was tried, but it did not keep the flow constant. In September 1977 it was decided that a flowmeter should be installed that could be used to monitor the total flow into the laboratory. In this way, there would be a continuous record of the flow, which could be used to ascertain if any parameters were flow-dependent. A turbine-type flowmeter (CE in-Val-Co Model W3/0750, 1-10 gal/min), with analog readout and output (CE in-Val-Co Model 531-1C frequency to analog converter) was installed in the main influent line to the mobile laboratory downstream of the totalizing water meter. The output from the flowmeter has been logged by the computer since Location 13.

MOBILE LABORATORY COMPUTER SYSTEM

General

The mobile laboratory is equipped with an on-board minicomputer system designed to log the data output from the various monitoring systems, and control the operations of some of the monitors. The computer system includes a Texas Instruments (TI) digital minicomputer, Model 960-A; a TI Silent 700 teleprinter; a Remex combination high-speed paper tape reader/perforator; and a Computer Products programmable wide-range analog-to-digital (A/D) converter, Model RTP 7480.

The computer contains 24K of semi-conductor core memory with a battery backup that will maintain the core memory for several hours during a power failure or when the mobile laboratory is moved from one location to another and the power must be shut off. This eliminates the need to completely reprogram the computer each time the unit is moved. During all of the MWD field work, memory was never lost while moving between locations, even with power off for periods of 3 to 4 hours. The computer has two 8-channel multiplexer boards mounted in the A/D converter for data input and a 16-channel input/output digital switching card for computer control operation.

Worker Tasks

The original computer system as set up and programmed by NSF is described in greater detail in that project report (5). The original NSF system, both hardware and software, had been modified by the EPA before MWD received the grant for this study. Within the computer, all program operations are under the control of the TI supervisor program PAM (Process Automation Monitor). Worker task programs, written to carry out the functions of the computer, are installed in the computer and operate under the control of PAM. Ten worker tasks had been written for the operation of the mobile laboratory computer by NSF and/or EPA. The seven worker tasks used during this study are as follows:

1. NSFC is a program containing utility routines, such as a decimal core dump routine.

2. INIT initializes output storage areas, checks punch (PUN) and starts the data acquisition (DAQ). It is used for start-up when the system is initially loaded.

3. DAQ is the basic data acquisition program which reads the various analog input channels and stores the digital values in a data buffer. DAQ contains the gains to be used by the A/D converter when reading each analog input channel.

4. DATA obtains data from the DAQ buffer area and stores it in an output storage area.

5. PUN outputs data from the output storage area of DATA and clears that area for fresh data. DATA unsuspends PUN wherever more data is put into the output storage area and suspends PUN when the data output is complete. Data can be output to either paper tape or the printer.

6. CONTAB has calibration data for a number of monitoring systems. The free and total residual chlorine were the only parts of this program used for this study. This calibration data is used by the CONMN worker task. The calibration data for the chlorine system is the slope and intercept from a calibration curve.

7. CONMN is a conversion program which takes the latest data from output buffer, calculates values for the parameters in engineering units, and generates a report that is output to the printer.

The DAQ Worker Task

The DAQ (data acquisition) worker task is the program which controls the gathering of data from the various monitoring systems. It controls what data is collected and the time sequence between data samples. The DAQ task was originally written by NSF and later modified by EPA. It was further modified by the MWD project staff in order to increase the efficiency of data collection and to improve the monitoring capability of the computer.

The computer monitoring system was used as is for the first five monitoring sites. During this time a number of inherent problems were observed in the system. The original DAQ program was set up to read 16 channels of input and output 23 different pieces of information, that is, several input channels were used to gather more than one piece of information. The basic sampling cycle was over 21 minutes and samples of various parameters were made at the end of each wait period in a sequence of 4, 6, 4, 7 minutes. During these 21 minutes, 41 readings were taken and punched onto the paper tape. However, 9 of the 41 punched readings were for parameters that were no longer used, but the computer still gave a print out indicating no data for them. Under this sampling regime a thousand-foot roll of paper tape for the output would last a maximum of 34 hours. Considering that operators were at the mobile laboratory only during normal working hours, this necessitated servicing the computer once a day in order to change the paper tape. Such daily attention required considerable overtime on weekends, however, it was not practical since the field sampling for the project was to last for a year. There were two alternatives, first was not to sample over weekends, or second to change the sampling cycle and regime. Since it is desirable to have uninterrupted data in order to observe possible weekend quality changes the only choice was to change the computer sampling procedure. This meant that the DAQ worker task would have to be modified.

Since the MWD project staff had only a basic amount of computer training and no specific experience on this TI system, it was difficult to reprogram the computer after it was decided that changes would improve the utility of the mobile laboratory. The computer system came from the EPA without a compiler or assembler and thus all programming changes had to be made at the machine code level. The first modifications that were made altered the sampling sequence and eliminated extraneous data from the paper tape output. With the altered DAQ worker task, readings for only the parameters of interest are taken and punched on the paper tape every 10 minutes. With 8 parameters being monitored, this extended the length of time that a roll of paper tape ran to 68 hours and eliminated the need for daily servicing of the computer. The mobile laboratory could then operate unattended over a normal 2-day weekend. The procedure to make the necessary changes (patches in the original DAQ program) was relatively easy, although somewhat troublesome and time consuming. The patches had to be manually entered into memory via the teleprinter whenever the computer needed to be reprogrammed.

After spending considerable time studying the computer and its programming, a technique for generating new worker task programming tapes was developed and implemented. Any new changes in worker task programs need only to be entered into core memory once, after which a new programming tape is made.

As the project progressed, additional changes were made in the DAQ program. One such change simplified the operation to alter the sampling cycle time. A single number, entered into a specific memory location via the teleprinter is presently the only operation needed to change the sampling cycle time. After this DAQ program change was made the standard sampling cycle was 10 minutes, however, it became convenient to change to a 12 minute cycle over standard 2-day weekends and appropriately lengthen the cycle to 14 or more minutes for a 3- or 4-day weekend.

A second change in the DAQ worker task was made that increased the utility of the computer by enabling it to record more data. A number of input channels were made available because the ASV and ion-selective electrode monitoring systems were not being used. Some of these spare channels were put to use recording data from other monitoring systems. Since not all input channels were read in the same sampling sequence, major revisions in DAQ as well as some minor revision in the DATA program were needed in order to make this change. The following systems were added to the computer for data recording:

1) CCDT on channel 1, starting with sample Location 6

2) HF turbidity on channel 2, starting with Location 7

3) Corrosion rates on channel 11, starting with Location 11

4) Flow to the lab on channel 12, starting with Location 12.

The two monitoring systems, CCDT and corrosion rate, were not being recorded by the computer when MWD received the mobile laboratory. Raw data from these two monitors were recorded on strip charts from which the final data had to be manually calculated. This data was then recorded on keypunch transmittal forms from which data cards were subsequently punched. This punched-card data could then be computer-analyzed and stored as with the paper tape data. The other two monitoring systems, HF turbidity and flow, were added to the monitoring capability of the mobile laboratory by MWD (discussed earlier in greater detail).

For three of the monitoring systems, CCDT, HF turbidity, and flow, the connections for computer recording were easy to make since no special alterations in the instruments were necessary. All three instruments had continuous analog outputs which were put directly to the inputs of the computer's analog-to-digital converter.

Even though continuously recording the CCDT by computer posed no special problem, measurements were still not continuous because when the test finished, the instrument had to be manually stopped and restarted. This was to allow cleaning of the gold disc electrode with dilute HC1. Near the end of the project, the CCDT was completely automated. The DAQ worker task was reprogrammed to control the acid washing of the electrode by controlling the operation of several solenoid valves and a pump for the acid. (See Appendix A for program listing and flowchart for DAQ MWD3.) This CCDT automation modification was put on line at Location 27 about halfway through the monitoring period.

The primary items needed for automating the CCDT were: a small DC pump (Micropump Corp., Paragon Division) for pumping the electrode cleaning acid to and from the cell; four solenoid valves (Skinner Valve Co.) for switching flows to the cell; and a 24VDC power supply for operating the DC pump. Because the pump operates on DC power, the direction of acid flow can be changed by reversing the polarity of the DC source voltage. Since 250 ml of dilute HC1 are required for each wash, changing the direction of flow was a necessity for reducing the amount of HC1 consumed during the cleaning operation. With the reversible pump, the same acid can be used repeatedly, by pumping from a reservoir to the electrode cell and back to the reservoir, with a great savings in chemical consumption. The solenoid valves are used to start and stop the test water flow to the CCDT cell, drain the cell, start and stop the acid feed, and to bypass the acid reservoir. The bypass valve is necessary so that the line and pump can be backwashed with tap water in order to eliminate residuals of the dilute HC1 that might damage the pump. The acid feed solenoid valve cannot be backwashed, however, it is teflon lined and is not attacked by dilute HC1.

The solenoid valve coils are activated by 110AC voltage and could not be operated directly through the computer digital output (DO) card. The DO card can only be used to switch DC voltages up to 24V. An external relay board was assembled with 11 miniature 24VDC relays (10 SPST and 1 DPST) that could be activated from the computer DO card. These relays are then used to switch the 110VAC to activate the solenoid valves, to switch the 24VDC to start and stop the acid pump, and to change the polarity of the DC voltage to the pump (the DPST relay). Figure 6 shows a schematic diagram of the relay control board and the CCDT automation setup. It was found that the coils of the relays operated by the computer DO card had to be protected with a diode. Otherwise, electronic noise from the relay coil operation would feed back through the DO card to the computer and cause interrupts that would halt the computer so that it needed to be completely reprogrammed.

Recording the data from the corrosion rate meter (CRM) by the computer was also no serious problem, since the analog output from the CRM was no different than that from the other instruments. The CRM measures eight different corrosion rates, i.e., anodic and cathodic corrosion rates at four different stations. In normal operation the CRM makes each of the eight measurements at a given frequency as set on a timer on the CRM. The main problem arose in trying to synchronize the CRM timing cycle with the computer data sampling cycle. This situation was resolved by having the computer take preference over the internal clock for cycling the CRM.

The CRM was not designed for this type of operation and the instrument had to be modified to accept external cycling control. It was observed that the CRM instrument cycles to the next station whenever the AC power is turned off by the main on/off switch. The modification was made by installing a 24VDC relay into the CRM chasis which could be controlled by the computer and used to turn off the main AC power to the CRM, thus cycling the instrument. One relay from the relay board described earlier, Figure 6, was used for the CRM cycling.

After the instrument was properly modified, the DAQ worker task had to be reprogrammed to control the instrument cycling as well as take the readings. The program is now written so that after all the instruments have been sampled the CRM relay is activated for a short period which turns off the AC power, thus advancing the CRM to the next station. It should be noted that the Petrolite Instruments Corp. (manufacturer of the CRM) approved of this modification for computer control of the unit and also verified that it would not damage the instrument or alter the measurements. The change in no way altered the instrument from operating in the standard mode without the computer. When the CRM is not connected to the computer, or if the computer fails, the internal clock will control the cycling operation. In other words, the modification is merely a computer override.

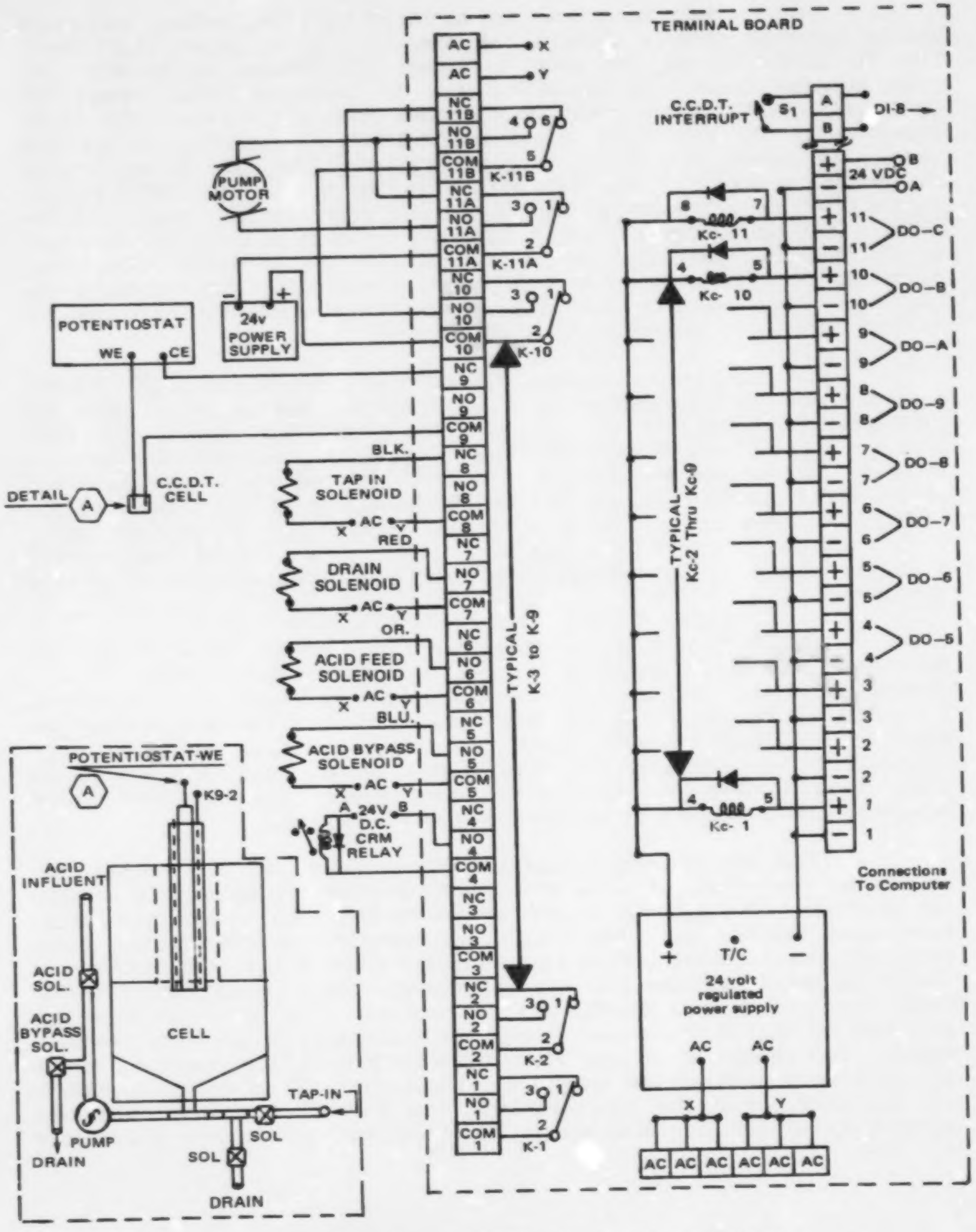

TERMINAL BOARD
AC
X
AC
Y
NC 11B
NO 11B
COM 11B
K-11B
NC 11A
NO 11A
COM 11A
K-11A
NC 10
NO 10
COM 10
K-10
PUMP MOTOR
24v POWER SUPPLY
POTENTIOSTAT
WE
CE
NC 9
NO 9
COM 9
BLK.
NC 8
NO 8
COM 8
TAP IN SOLENOID
DETAIL
A
C.C.D.T. CELL
RED
NC 7
NO 7
COM 7
DRAIN SOLENOID
OR.
NC 6
NO 6
COM 6
ACID FEED SOLENOID
BLU.
NC 5
NO 5
COM 5
ACID BYPASS SOLENOID
24V D.C. CRM RELAY
NC 4
NO 4
COM 4
NC 3
NO 3
COM 3
NC 2
NO 2
COM 2
K-2
NC 1
NO 1
COM 1
K-1
TYPICAL K-3 to K-9
POTENTIOSTAT-WE
K9-2
ACID INFLUENT
ACID SOL.
ACID BYPASS SOL.
CELL
PUMP
DRAIN
TAP-IN
SOL
SOL
DRAIN
C.C.D.T. INTERRUPT
S1
DI-8
24 VDC
Kc- 11
DO-C
Kc- 10
DO-B
DO-A
DO-9
DO-8
DO-7
DO-6
DO-5
TYPICAL Kc-2 Thru Kc-9
Kc- 1
Connections To Computer
T/C
24 volt regulated power supply
AC
AC
X
Y
AC
AC
AC
AC
AC
AC

Figure 6. Schematic diagram of CCDT automation relay control panel.

Computer Cooling Problems

During the hot summer months, until the installation of the second air-conditioner (discussed earlier), the mobile laboratory would warm up to extreme temperatures. At the same time the computer would get very hot, in excess of the limits recommended by the manufacturer. There was no circulation within the computer cabinet and thus no way to vent the heat generated by the various computer hardware components; primarily the CPU and the paper tape reader/perforator. The second air-conditioner helped considerably by decreasing the ambient air temperature around the computer cabinet. However, it was decided that this was not sufficient, so a small circulating fan was installed inside the top of the computer cabinet. In addition, a portion of the cabinet top was cut out and replaced with a filter and screen. This further allowed for increased circulation by providing for a vent at the top of the cabinet through which hot air could escape. It should be noted that even though the computer CPU got extremely hot (120° F) at times during the day, no problems were experienced that were due to overheating. The computer should be commended as it operated extremely well with less than optimum operating conditions (large changes in temperature and bouncing around in a mobile laboratory) and no problems were experienced that could be related to these adverse conditions.

SECTION 5

DATA HANDLING AND PRESENTATION

PAPER TAPE DATA

The main source of raw data from the mobile laboratory monitoring systems is the paper tape output from the on-board computer. As was stated in an earlier section of this report, a considerable volume of paper tape data was generated by the computer every day. At first, approximately 700 feet and later, after the program changes, approximately 350 feet of paper tape was punched every 24 hours. The paper tape reader/punch unit does not have a takeup reel for the punched tape and thus this tape would merely pile up on the floor in front of the computer. Since the reader/punch unit has only a small wheel for winding up tape, a considerable amount of time would have to be spent in rolling up the punched tape by hand. The MWD project staff designed, had constructed, and installed on the side of the computer cabinet a paper tape winder that would handle a whole roll of paper tape. The winder saves handling time and can be used to wind up the tape during the day and thus eliminate the clutter of tape on the floor.

The preparation of tabulated listings of the raw data was to be done with the IBM-370-138 computer in MWD's Data Processing Center. However, this computer is not able to use paper tape input. This meant that before the mobile laboratory data on paper tape could be analyzed it had to be first transposed to magnetic tape, an input media which the IBM-370 will accept.

The transposing of the paper tape data to magnetic tape was done by MWD's Centralized Control Section which has a Lockheed MAC-16 minicomputer system with both a paper tape reader-punch and a magnetic tape unit. Since there was no existing conversion program, the Centralized Control staff had to write the necessary program to handle the transposition of the data between the two media. The program was written such that the data is stored on the magnetic tape in large blocks which minimizes the amount of tape needed to store the data from each location. It was written to be flexible enough to handle various data situations that might arise, such as being able to eliminate the data from certain parameters on the paper tape that are invalid due to instrument malfunctioning or some other reason.

A major revision to the transfer program was necessary when the corrosion data was added to the records stored on paper tape. All the corrosion data was punched on the paper tape as parameter number 11, however, this data represented 8 different corrosion rates, i.e., anodic and cathodic corrosion rates on the 4 CRM channels, mild steel, zinc, copper, and a 10-mil-per-year instrument test standard. Each of these eight corrosion rates had to be assigned new parameter numbers and in order to carry out this parameter number reassigning properly, the MAC-16 computer had to be told for each paper tape roll what number to assign to the first parameter 11 on each roll. After the first number is known, then each of the other seven numbers come in the same repeated sequence. Also, the recorded value from each CRM channel had to be multiplied by an appropriate sensitivity factor depending on how the sensitivities were set on the CRM for that channel. Thus sensitivities for each of the four CRM channels (anodic and cathodic corrosion for a given metal are on the same sensitivity) also had to be entered to the MAC-16 before the proper transfer of data could be accomplished.

Since there was a significant possibility for error in either recording or entering all the information needed for the data transfer (beginning channel number and sensitivities) a check was added to the program that would catch errors. Every fourth corrosion value was either the anodic or cathodic 10-mil-per-year test standard. Thus, an easy check was to make sure that the standard points were there and that they were within certain limits. This data check was quite helpful in catching errors that would have otherwise caused considerable amount of extra time to locate and correct.

RECORDER CHART DATA

Throughout the duration of the project there were always a number of parameters that were not recorded by the computer and thus not on the paper tape. At first there were more parameters recorded manually than recorded by the computer, but as the capabilities of the computer were improved and expanded, the volume of manual data decreased. However, there have always been titration data and this could not be recorded by the computer. As was stated earlier in the report, the manually recorded data had to be listed on data transmittal forms, from which the data were punched onto computer cards. The IBM-370 can accept computer card data as well as the magnetic tape data generated from the paper tapes. The card data from each monitoring location had to be merged with the magnetic tape file of the paper tape data, thus producing one final magnetic tape file for that location. Computer listings, graphing, and other analysis could be done on all of the data together using this file. The Data Processing Center personnel wrote the programs necessary to merge the card data with the magnetic tape data.

DATA PROCESSING

The EPA had developed a computer program (written in Fortran) that would take the paper tape data from the mobile laboratory minicomputer and make both a printed listing and a graphical plot of the parameters versus time. MWD's Data Processing Center staff used this program as the basis for the general data processing of the field data for MWD's monitoring project, however, it had to be greatly modified and expanded. Some of the parameters for which the EPA program was written were not monitored in the MWD study, and other parameters were added to the monitoring capability of the mobile laboratory. The program had to be modified to compensate for these changes.

The program takes the number which was recorded on the paper tape for each parameter and converts it to the actual value in the appropriate engineering units and uses these final values for the listings and plots. The numbers on the paper tape are in analog-to-digital units (ADU), which are the values from the analog-to-digital (A/D) converter and are proportional to the instrument signal voltage depending on the gain of the A/D converter when it reads the instrument. The conversion program must include the A/D converter gains for each data channel plus a means of converting ADU's to actual engineering units.

For converting some parameters, simply multiplying by a conversion factor is all that is needed. Other parameters require a slope and intercept calculation from a calibration curve. The signal from the Hach turbidimeter is non-linear, and thus turbidity had to be calculated from a table stored in the computer. The table prepared by the NSF programmers was used at first, however it was not completely satisfactory. The table was a step rather than a continuous function and was not set up for turbidities greater than 0.65 turbidity units (TU). The MWD project staff and Data Processing staff together made a new turbidity table for the full range 0-1.0 TU and calculated a best-fit equation for a set of turbidity values. This equation was then used to convert the ADU value from the Hach instrument to turbidity units.

The data processing program had to be first modified to accept magnetic tape input. Later on it was also modified to merge the card data with the magnetic tape data, producing the final magnetic tape record of all the data. This final tape was then used for the converting, listing, and plotting. The program was also modified to allow for the omission of data segments that have been determined to be bad and would have otherwise biased the results.

The plot program was also modified to accept the changed data situation. Plotting of the data versus time was done on a Houston Instruments Complot DP-7 plotter which has three pens for multicolored plots. All plots are made on graph paper rolls with a 10 x 12 lines to the major grids, which is well suited for plotting by the day with one-hour divisions. The plotting format was changed to graph several parameters in different colors on the same sheet and to add other pertinent information, such as location name, year monitored, and, on the time axis, actual calendar dates. It takes two different graphs (A and B) to include all the various parameters monitored. Reduced-scale illustrations of each computer-plotted graph for a 5-day period at Location 25 are shown in Figures 7 and 8.

The data for parameters that are taken on the 10-minute computer data sampling sequence are plotted as a continuous curve. The pen is lifted and the curve stopped any time there is a pause in data greater than 20 minutes. Data taken at a less frequent rate is plotted on a curve with tick marks indicating actual data points.

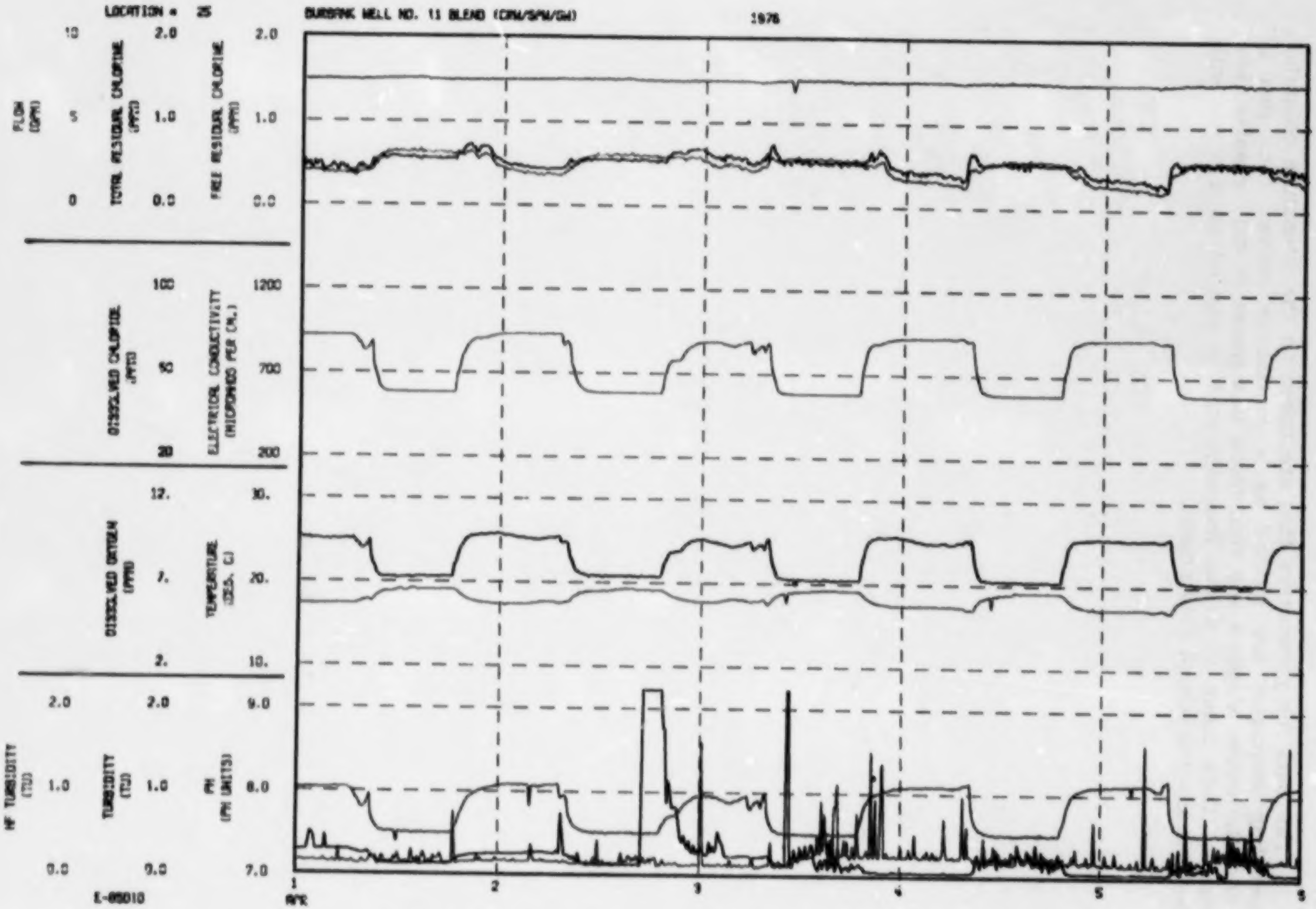


Figure 7. Computer-plotted water quality data at Location 25 – Graph A.

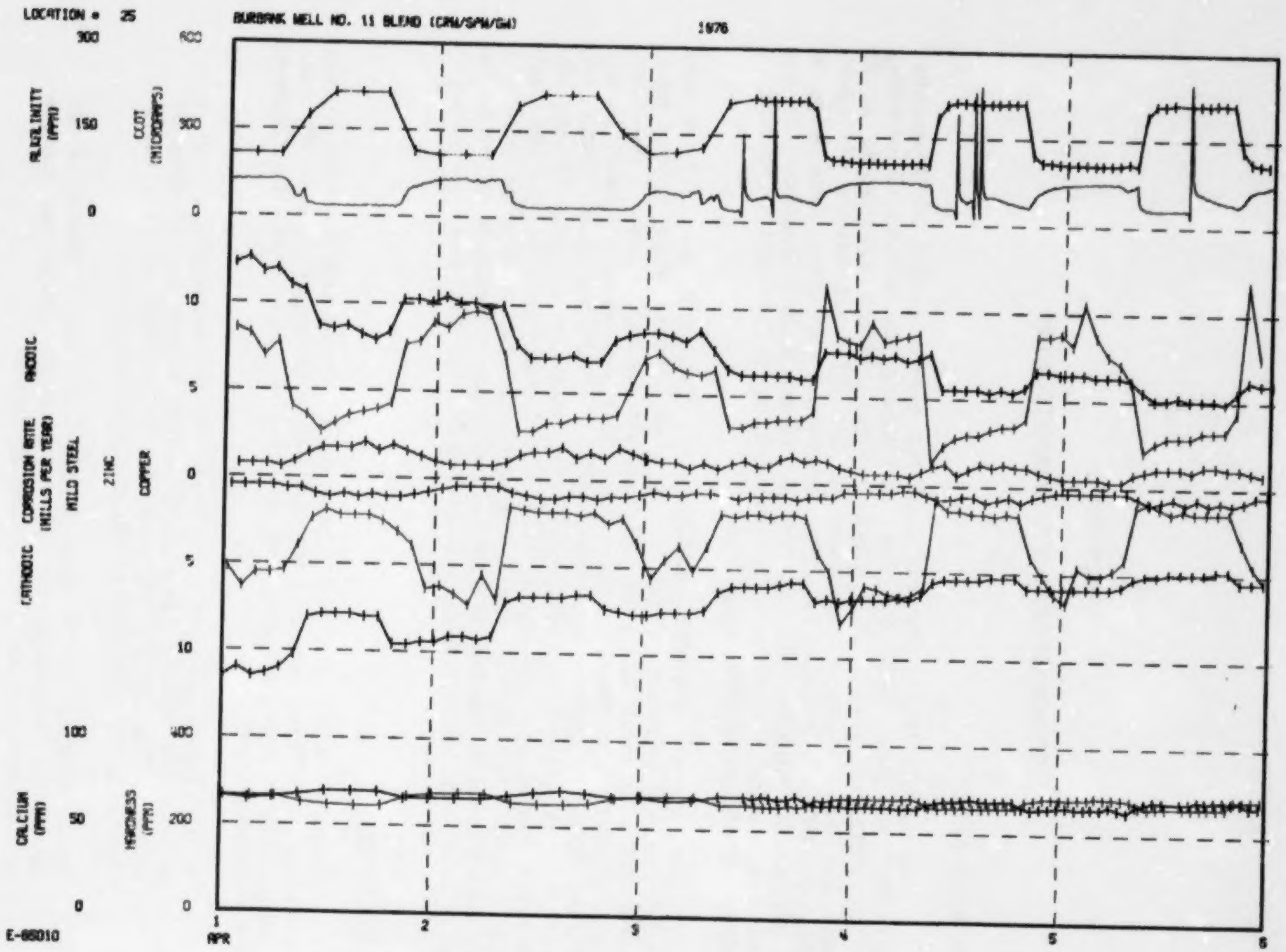


Figure 8. Computer-plotted water quality data at Location 25 – Graph B.

SECTION 6

EXPERIMENTAL FIELD MONITORING

MONITORING SITES

The mobile laboratory was deployed over a period of 18 months, January 1977 to June 1978, for field monitoring the effects of blending waters of different quality and origin. Field studies were made at 30 different locations, representing many of the different blends of waters available in MWD's service area. Six additional test runs were made at MWD's Weymouth filtration plant. The list of monitoring locations and the type of water monitored is given in Table 2, with comments pertaining to the location or the parameters monitored.

The severe drought conditions in California in 1977 imposed constraints on the selection of monitoring sites because State project water was unavailable at most locations where it was normally used. Moreover, none was available for blending with Colorado River water at the Weymouth and Diemer filtration plants from March 1977 to February 1978. Figures 9, 10, and 11, respectively, show the system delivery patterns during the pre-drought period prior to March 1977, the drought period, and the post-drought period after March 1978. The general location of sites monitored during each period in relation to water distribution patterns is shown in the above figures; the circled numbers correspond to the locations listed in Table 2.

Site Operating Conditions

Potential monitoring locations were reviewed and selected to meet the operating conditions required for the mobile laboratory. Both MWD and the cooperating water agencies had to provide sites with the following utilities and conditions:

1) A continuous flow of the water to be monitored, 6 to 8 gallons per minute (gpm), preferably 8 gpm for 10 days or longer. The 6-gpm minimum flow is needed to have sufficient velocity past the dissolved oxygen electrode.

2) Power supply of 20 amp at 240 VAC single phase or an equivalent amperage at 480 VAC single phase to operate instruments and air-conditioning equipment.

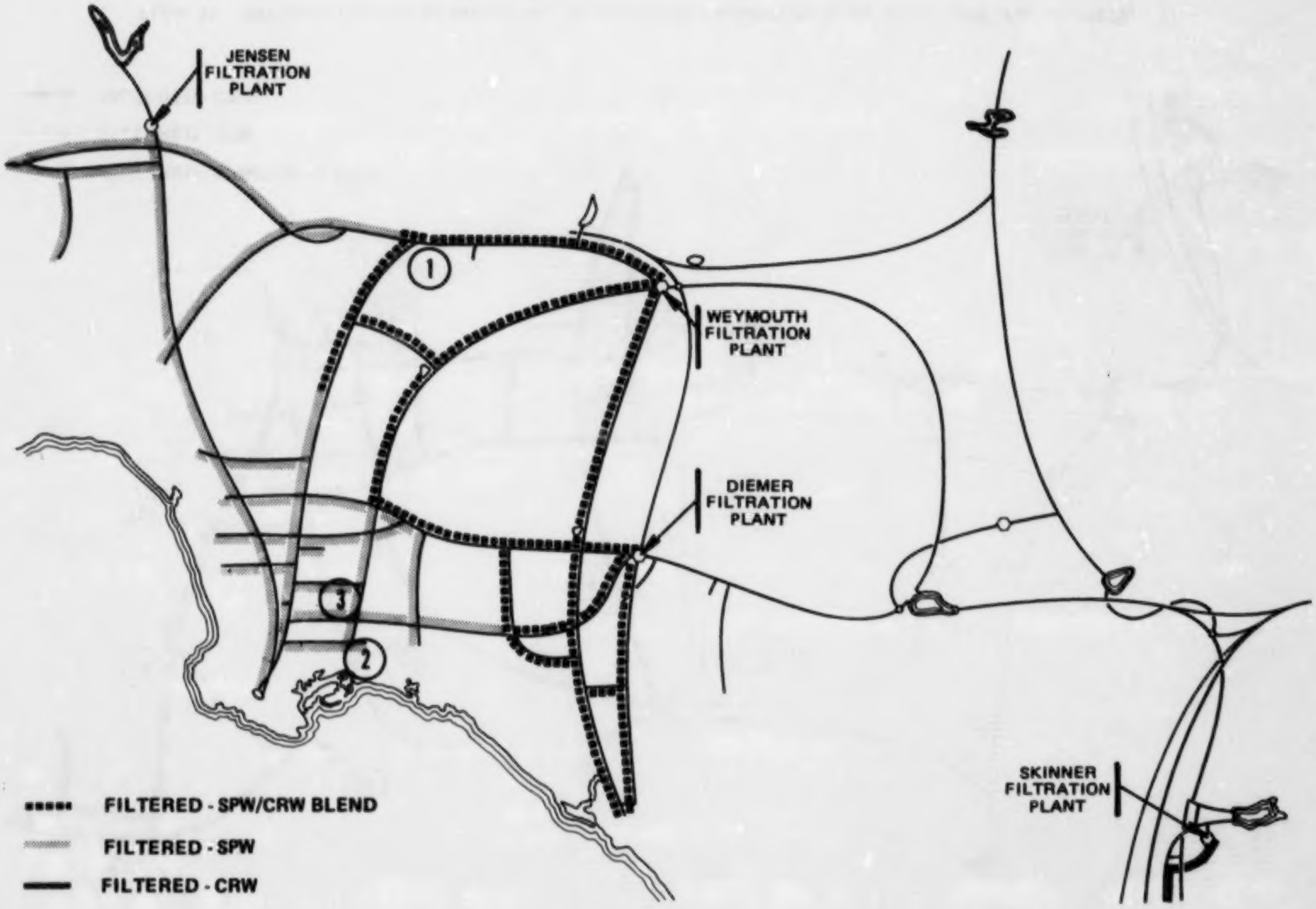

JENSEN FILTRATION PLANT
WEYMOUTH FILTRATION PLANT
DIEMER FILTRATION PLANT
SKINNER FILTRATION PLANT
①
②
③
FILTERED - SPW/CRW BLEND
FILTERED - SPW
FILTERED - CRW

Figure 9. MWD system delivery pattern showing monitoring locations—Pre-drought period (before March 1977).

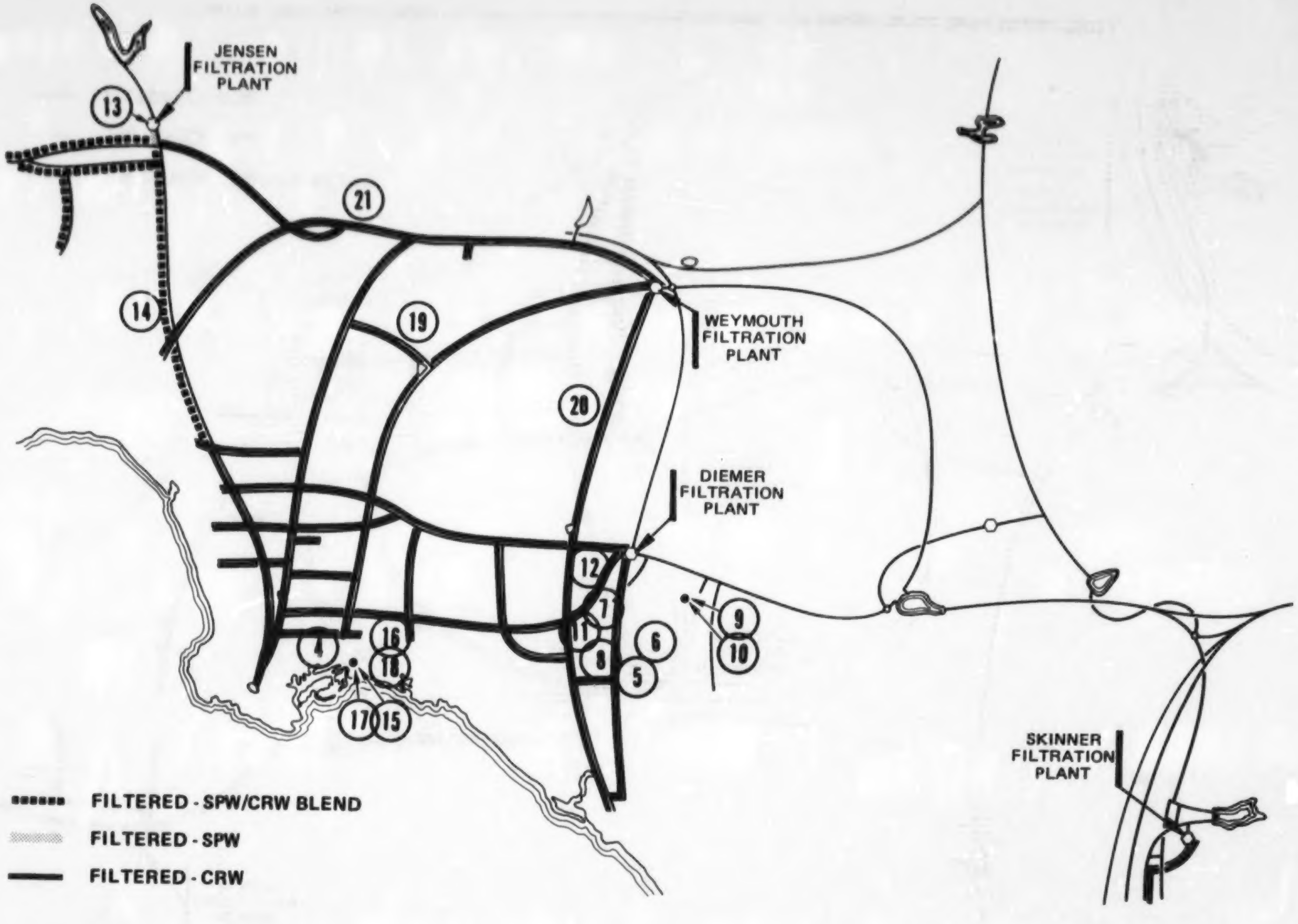

JENSEN FILTRATION PLANT
13
21
14
19
WEYMOUTH FILTRATION PLANT
20
DIEMER FILTRATION PLANT
12
7
11
8
6
5
9
10
4
16
18
17
15
SKINNER FILTRATION PLANT
FILTERED - SPW/CRW BLEND
FILTERED - SPW
FILTERED - CRW

Figure 10. MWD system delivery pattern showing monitoring locations—Drought period (March 1977—February 1978).

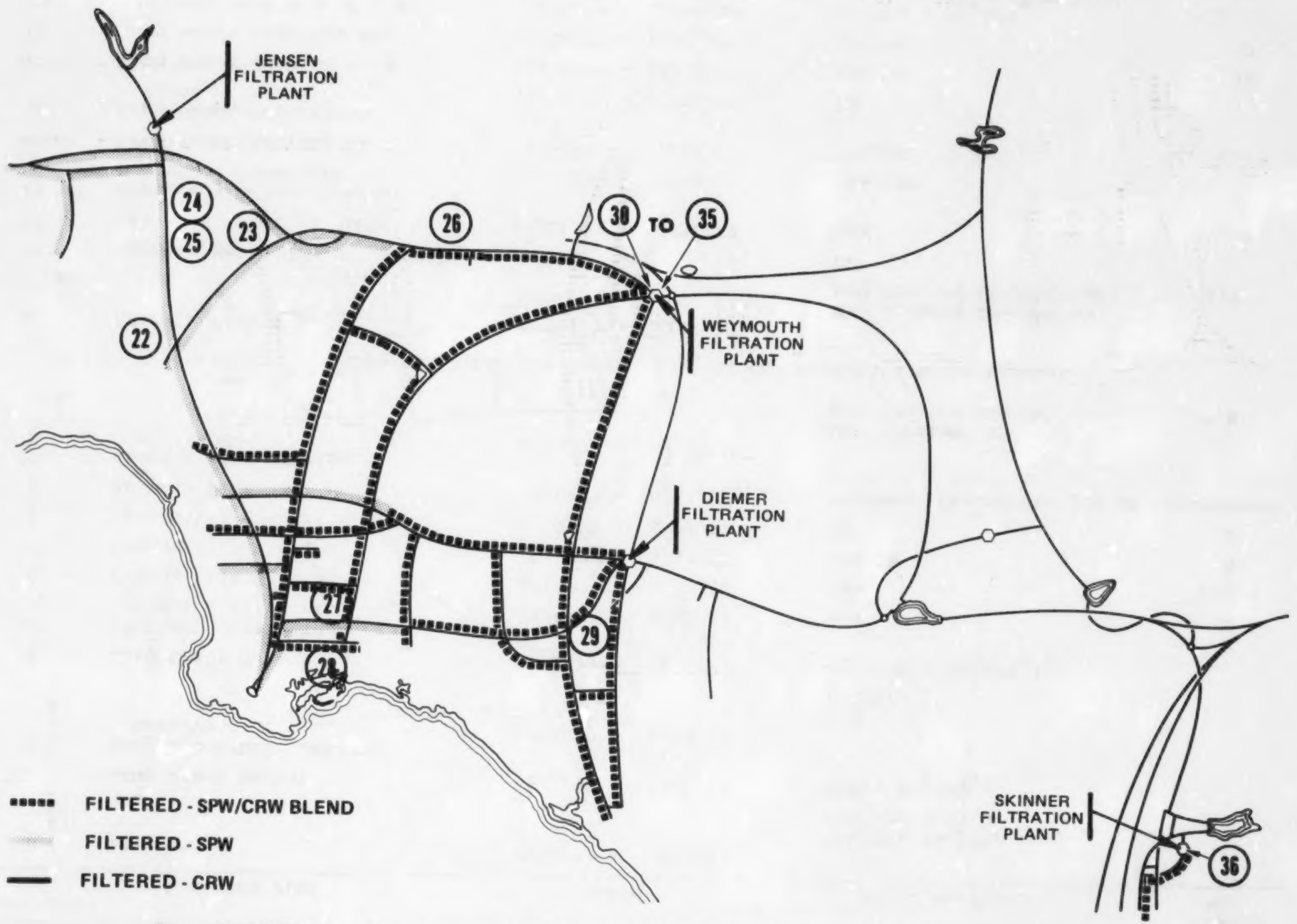

JENSEN FILTRATION PLANT
24
25
23
22
26
30 TO 35
WEYMOUTH FILTRATION PLANT
DIEMER FILTRATION PLANT
27
28
29
SKINNER FILTRATION PLANT
36
FILTERED - SPW/CRW BLEND
FILTERED - SPW
FILTERED - CRW

Figure 11. MWD system delivery pattern showing monitoring locations—Post-drought period (after March 1978).

TABLE 2. MOBILE LABORATORY FIELD MONITORING LOCATIONS

Location No.	Location Name	Dates	Water Analyzed	Comment No.
1	Pasadena	1/24/77 - 2/7/77		
a)			CRW/SPW/GW(low)	
b)			CRW/SPW/GW(high)	
2	Long Beach Harbor	2/7/77 - 2/11/77	SPW + $Zn_3(PO_4)_2$	
3	Long Beach-Will Johnson Reservoir	2/11/77 - 2/23/77		
a)			SPW	
b)			CRW/SPW	
4	Long Beach Harbor	2/23/77 - 3/7/77	CRW/SPW + $Zn_3(PO_4)_2$	
5	Santiago Creek Pressure Control Structure	4/4/77 - 4/18/77	CRW	1
6	Orange Fire Sta. No. 4	4/18/77 - 4/20/77	CRW	2,3,4
7	Orange Fire Sta. No. 3	5/9/77 - 5/19/77	CRW/GW	5
8	Orange Well No. 14	5/19/77 - 5/28/77	GW	6
9	Anaheim Fire Sta. No. 8	6/6/77 - 6/15/77	Anaheim Treated CRW (no pH adjustment)	
10	Anaheim Fire Station No. 8-OH	6/15/77 - 6/27/77		
a)			MWD Treated CRW	
b)			MWD Treated CRW/GW	7,8
	Locations 11a through 19 had the ground loop in the corrosion meter circuit			
11	Anaheim Fire Sta. No. 7	9/16/77 - 9/27/77		
a)			MWD Treated CRW/GW(low)	
b)			MWD Treated CRW/GW(high)	8,9
12	Anaheim Wells Nos. 27 & 28	9/28/77 - 10/7/77	GW	
13	Jensen Filtration Plant	10/11/77 - 10/21/77	SPW	10,11
14	Sepulveda Canyon Pressure Control Structure	10/21/77 - 11/2/77	CRW/SPW	
15	Long Beach Service Yard	11/7/77 - 11/16/77	CRW/GW + $Zn_3(PO_4)_2$	
16	Long Beach Filtration Plant	11/16/77 - 11/30/77	GW	
17	Long Beach Service Yard	11/30/77 - 12/12/77	CRW/GW	12
18	Long Beach Alamitos Res.	12/12/77 - 12/22/77	CRW/GW	12
19	Alhambra Fire Sta. No. 4	1/5/78 - 1/16/78	CRW/GW + $Zn_3(PO_4)_2$	

(Continued)

TABLE 2 (Continued)

Location No.	Location Name	Dates	Water Analyzed	Comment No.
20	Walnut-Libby Glass Co.	1/30/78 - 2/8/78	CRW + $Zn_3(PO_4)_2$	13
21	Foothill MWD	2/8/78 - 2/22/78	CRW	14
22	Sepulveda Canyon Pressure Control Structure	2/22/78 - 3/7/78	SPW	14
23	Burbank Service Yard	3/7/78 - 3/17/78	CRW/SPW	14
24	Burbank Well No. 11	3/21/78 - 3/30/78	GW	6,14
25	Burbank Well No. 11 Blend	3/30/78 - 4/11/78		
a)			CRW/SPW/GW(low)	
b)			CRW/SPW/GW(high)	8,14
26	Foothill MWD II	4/11/78 - 4/21/78	CRW/SPW	14
27	Long Beach-Will Johnson Reservoir	5/4/78 - 5/16/78	CRW/SPW	14,15
28	Long Beach Harbor	5/16/78 - 5/30/78	CRW/SPW + $Zn_3(PO_4)_2$	14
29	Anaheim Fire Sta. No. 7	5/30/78 - 6/8/78		
a)			CRW/SPW/GW(low)	
b)			CRW/SPW/GW(high)	8,14
30	La Verne Test 1	6/8/78 - 6/22/78	CRW/SPW (no pH adjustment)	16
31	La Verne Test 2 Repeat of Test 1	6/22/78 - 7/1/78	CRW/SPW (no pH adjustment)	16
32	La Verne Test 3 Continuation of Test 2 Varying Flow	7/7/78 - 7/27/78	CRW/SPW (no pH adjustment)	16
33	La Verne Test 4 Continuation of Test 2 On & Off Ground Loop	7/27/78 - 8/15/78	CRW/SPW (no pH adjustment)	16
34	La Verne Test 5 Repeat of Test 1	8/17/78 - 9/7/78	CRW/SPW (no pH adjustment)	16
35	La Verne Test 6 Repeat of Test 1, but with Ground Loop Continuously	9/7/78 - 9/25/78	CRW/SPW (no pH adjustment)	17
36	Skinner Filtration Plant	10/2/78 - 10/26/78	CRW/SPW	18

Comments Related to Table 2

1. Start water sampler for hourly samples for hardness, calcium, and alkalinity titrations.
2. Start new computer time sequence -10 min. cycle time.
3. Start recording CCDT on Computer CH-1.
4. Corrosion meter problem, suspended monitoring on 4/20/77.
5. Start recording HF turbidity on Computer CH-2.
6. No residual chlorines; no Cl_2 added to well water.
7. Malfunction of A/D converter on Computer 6/21/77.
8. Marked diurnal fluctuations in quality due to in-line blending of the 2 waters.
9. Start recording corrosion on Computer CH-11.
10. Start constant head control of flow to corrosion cells.
11. Start recording flow on Computer CH-12.
12. Locations Nos. 17 and 18 are the same water as No. 15 but without zinc; that is, the zinc feed was stopped. Monitoring was not started until the zinc level at the monitoring site had decreased to near background levels. However, the water had to flow through 5 to 10 miles of previously pacified delivery mains to get to Location 17. Since there was a possibility of long-term residual effects due to zinc being in the delivery mains, it was decided to monitor at Location 18 which is only about a mile downstream from where the zinc is added.
13. Corrosion ground loop discovered and corrected by using an external power supply for the corrosion meter relay.
14. Chloride monitor breakdown; chloride values taken from daily grab samples.
15. CCDT automation started, halfway through monitoring at Location 27.
16. Recorded only pH, EC, DO, Temp, corrosion rates.
17. Added CCDT to parameters listed in 16.
18. All parameters monitored except Chloride.

3) Drain, essentially at ground level, to dispose of wastewater from the laboratory by gravity flow from 1-1/2" PVC drain pipe.

4) Fenced parking area to secure laboratory from vandalism.

In addition to meeting the above conditions, sites were selected where the cooperating water utility could modify water distribution patterns to vary the sources of water, or in a few cases to temporarily discontinue feeding of corrosion inhibitor chemicals to observe subsequent effects on the parameters being monitored.

Prior to moving to a new location, the potential site was visited and surveyed to make sure the necessary utilities were available and that the other conditions were met. In this way any necessary alterations in the site or necessary preparative work could be done in advance of bringing in the mobile laboratory. Packing up the lab at one location, moving, and setting up at the new location generally required one day. Packing up and setting up each took about an hour when the necessary site preparations had been made. It must be remembered that the time for changing locations had to be kept to a minimum, because the battery back-up which holds the computer memory is only good for approximately 4 hours. The electrical power was, therefore, the last utility disconnected and the first one connected when changing locations.

The mobile laboratory was leveled and stabilized at each site by the use of four screw jacks placed under the frame of the vehicle. If much leveling was necessary, the laboratory was driven up on blocks after which fine adjustments were made with the jacks.

PARAMETERS MONITORED

Table 3 is a list of the parameters monitored during this study. The table lists the parameter, the frequency with which it was measured, and the technique used to make the measurement. In addition, daily grab samples were taken back to the MWD central laboratory for analysis and a check on values obtained by the mobile laboratory instruments. Daily comparisons were made on pH, conductivity, turbidity, and dissolved chloride. These daily chloride values became of greater value later in the project when the chloride monitor was malfunctioning.

SAMPLING FOR MANUAL AND SPECIAL ANALYSIS

Calcium, hardness, and alkalinity were monitored by manual titrametric techniques. The samples for these parameters were taken by the 24-bottle sampler (Sigmamotor). The sampling frequency varied, however in general samples were taken hourly during the week and every 3 hours over the weekend. The sampler collected about 200 ml of water in 250-ml polyethylene bottles. Analyses were made daily on the previous day's samples.

TABLE 3. PARAMETERS MONITORED FOR MWD MOBILE LABORATORY PROJECT

Parameter Name	Frequency of Analysis	Computer Channel Number	Methods of Analysis	Manufacturer if Commercial Instrument
1) Calcium Carbonate Deposition Test	Continuous*	1	Potentiostatic Rotating Ring Disc Electrode	Pine Instrument Co.
2) H-F Turbidity	"	2	Nephelometer	H-F Instruments Ltd.
3) Chloride	"	3	Solid-State Ion-Selective Electrode	Schneider Inst. Co.
4) pH	"	4	Glass Electrode	Schneider Inst. Co.
5) Conductivity	"	5	A-C conductivity cell	Schneider Inst. Co.
6) Dissolved Oxygen	"	6	Voltammetric Electrode	Schneider Inst. Co.
7) Temperature	"	7	Thermister	Schneider Inst. Co.
8) Free Residual Chlorine	"	8	Galvanic Cell Analyzer	Capital Controls Co.
9) Total Residual Chlorine	"	9	Galvanic Cell Analyzer	Capital Controls Co.
10) Hach Turbidity	"	10	Nephelometer	Hach Chemical Co.
11) Corrosion Rates Mild Steel Zinc Copper	"	11	Polarization Admittance Technique	Petrolite Insts. Co.
12) Total Flow to Lab	"	12	Turbine Flowmeter	C-E In-Val Co.
13) Hardness	every 1-4 hrs. from 24-bottle sampler	-	EDTA titration	-
14) Calcium	"	-	EDTA titration	-
15) Alkalinity	"	-	H_2SO_4 titration	-
16) Cadmium	2 or more/loc.	-	Graphite Furnace AA	Perkin-Elmer
17) Lead	"	-	"	"
18) Copper	"	-	Flame AA	"
19) Zinc	"	-	"	"
20) Iron	"	-	"	"
21) Manganese	"	-	"	"

*Continuous, i.e., every 10 to 12 mins.

The daily grab samples, which were used to check the mobile laboratory instrument readings against the central laboratory values, were taken in 2-liter polyethylene bottles. Before the sample was taken, the bottle was rinsed several times with the water to be sampled. The grab samples for trace metal analyses were taken in 125-ml polyethylene bottles with polyethylene caps. Both bottles and caps were prewashed with 1:1 nitric acid and rinsed thoroughly with deionized water (Millipore Corp, Super Q). Each bottle had 1 ml of clean 1:1 nitric acid added so that the sample, when taken, would be preserved until the time of analysis.

MONITORING PERIOD

The mobile laboratory was set up at each location for a period of about 10 days. It was thought that the 10 days was a necessary minimum period in which to obtain a good background of water quality data. This time period would allow for the observation of diurnal variations as well as weekend variations. This period was arbitrarily chosen; however, it was based on the fact that it takes some time to obtain meaningful corrosion rate measurements. Corrosion of a clean metal surface is greatly accelerated on the first contact with water giving a very high initial corrosion rate. The corrosion rate drops in an exponential manner and begins to stabilize in about a week, that is, the daily rate of change is at a minimum. It was hoped that the 10 days would be sufficient to obtain corrosion rates that would be comparable between the various monitoring locations.

CLEANING CORROSION ELECTRODES

Acid cleaning was used to remove corrosion products from the corrosion electrodes prior to the start of monitoring at each location. At first 20 percent hydrochloric acid (1:5 by volume) was used to clean all the electrodes (mild steel, zinc, and copper), however, it was observed that the copper electrodes were not completely cleaned of oxidation products by the dilute HCl. Subsequent to this observation, dilute nitric acid (1:1 by volume) was used to clean the copper electrodes. In all cases, the electrodes were dipped in the cleaning acid and held there until the visible gross deposits and corrosion products were removed. Brushing was also used to help clean the electrodes. Immediately after the acid washing, the electrodes were rinsed thoroughly in tap water to remove any traces of the cleaning acid. Extreme care was taken during cleaning to never touch the electrodes or, in some other way, get oil or grease on them.

CLEANING CCDT ELECTRODES

Until the CCDT was completely automated, the CCDT electrode had to be manually cleaned prior to the start of each CCDT run. Cleaning was accomplished by removing the electrode from the rotator and then putting a drop of hydrochloric acid (1:1 by volume) on the gold electrode. Any deposited CCDT film was instantly solubilized by the acid. Most films were carbonaceous and there would be a little fizzing after the acid was applied. The electrode was then rinsed with tap water. This acid-washing procedure was repeated once before the electrode was remounted in the rotator.

SPECIAL ATTENTION FOR THE CCDT

In the early stages of the project after the computer was used to record the CCDT data, every effort was made to manually start the test just before a reading was to be taken by the computer, that is, near the end of a 10 minute sampling cycle. In this manner an initial reading would be taken just after the test was started. However, this was not always easily accomplished. It was important to obtain this initial reading because some waters (those with zinc phosphate added) had very steep CCDT slopes and the whole test was nearly complete in 10 minutes. If the test was started in the middle of a sampling cycle, the test would be almost finished by the time the computer took the first reading. Midway through the project, a small program change was written for the DAQ worker task that allowed an external switch, connected to one of the digital input channels to the computer, to start and stop the test. When the switch was thrown in the appropriate direction the CCDT was either started, or stopped, several seconds before the reading was taken by the computer. Thus an initial reading was assured just seconds after the test was started.

INSTRUMENT CALIBRATION

The monitoring instruments in the mobile laboratory were periodically checked for accuracy, and calibrated when necessary. In general, most of the instruments needed little attention as to calibration. The residual chlorine analyzers needed to be recalibrated only once, however, monthly calibration checks were made using a Wallace and Tiernan amperometric titrator. The HF turbidimeter was checked daily against a standard and the meter was adjusted when needed. The Hach turbidimeter was then adjusted to read the same as the HF unit. The dissolved oxygen (DO) system was checked periodically against a Winkler DO titration. When the sensitivity of the electrode decreased significantly, the electrode was rebuilt according to the manufacturer's directions. After rebuilding, the DO system was calibrated against Winkler titrations.

Daily grab samples were collected in the mobile laboratory and taken back to the central lab where the pH, conductivity, turbidity, and chloride were measured and the values recorded. Values for the same parameters were recorded from the mobile laboratory instruments when the sample was taken, so that comparisons could be made which would indicate the need for calibration. The various monitors were adjusted when necessary.

INSTRUMENT PROBLEMS

During the field monitoring phase of the project, a number of instrumental problems and failures were experienced, some of which were responsible for periods in which no monitoring could be carried out. However, in most cases these pauses in the field monitoring program were put to good use in calibrating instruments and in making the previously described improvements in the monitoring equipment.

The first problem causing a time loss was due to a failure in the corrosion rate meter. The instrument had to be sent back to the factory for repairs. The problem was a defective power supply which was replaced. This caused a 3-week delay in monitoring.

The most serious time loss problem was a failure in the computer's analog-to-digital converter (ADC). Here again the piece of equipment had to be sent back to the manufacturer (Computer Products) for repair. However, this was handled through the equipment supplier, Texas Instruments, who had originally supplied the complete computer package. The extra handling caused by not dealing directly with the manufacturer caused additional delays in completing the repair. As a result, a total loss of nearly three months was experienced due to this particular instrument failure. Some of the delay was caused by the fact that there were no manuals or other documentation on the ADC. Subsequently, several manuals were purchased to provide this information.

A major problem was experienced with the corrosion rate meter (CRM) that caused no monitoring time loss, however, it did introduce a question as to the validity of the corrosion data collected while the undetected problem existed (from Locations 11 through 19). The problem was inadvertently introduced when the computer was set up to record the corrosion data and to cycle the CRM. As was stated earlier in the report, a 24VDC relay that would cause the CRM to cycle was installed in the CRM. An existing 30VDC power supply in the CRM was used as the supply voltage to operate the relay coil and a channel on the computer's digital out-card was used as the switch would complete the circuit and activate the relay. The manufacturer approved this alteration in the CRM and stated that it would not overburden the power supply. However, when the CRM was connected to the computer a very complicated and circuitous ground loop, that affected corrosion rates, was introduced into the corrosion measuring circuit. It was found that this ground loop included the digital out-board in the computer, the power supply in the CRM, the CRM measuring circuit, and the corrosion electrodes in the flow cells. When one part of this loop was broken, the effect was removed, as was the case when the CRM was measuring on the meter prover internal corrosion standard instead of on the electrodes in the flow cell. The initial testing of the computer cycling control was done using only the channel that was connected to the meter prover and thus no effect was noticed because the ground loop was broken. Since no anomalies were noted during the setup and testing it was assumed that there would be no erroneous readout when the CRM was set up to measure on the four channels. Thus no special attempt was made to look for possible problems. The only way to detect the problem was to observe the meter readout while one leg of the loop was broken and this was exactly how the problem was discovered. Some additional changes were being made in computer controlling other operations and the CRM control wires were disconnected from the digital out board of the computer. During this operation the CRM meter was observed to jump. The full extent of the problem was determined after further inspection. After it was identified, the ground loop effect was immediately eliminated by changing the power supply for the cycling relay from the one in the CRM to a power supply isolated from the CRM.

The ground loop had different effects on the corrosion rates for the three electrode materials and was not the same in the anodic and cathodic modes. Several tests have been carried out in an attempt to quantify the effect of the ground loop and to determine how best to interpret and/or correct the results obtained during the period when the ground loop was connected and affecting the corrosion rates. This was done by measuring the corrosion rates with the corrected circuit for the normal monitoring period; then, the corrosion rates were measured with the ground loop reconnected for one day near the end of each monitoring period. Having the corrosion rates measured under both conditions was helpful in interpreting the data collected while the ground loop was in the circuit.

Other minor problems were experienced with the following:

1) Recorder on the Petrolite Corrosion Rate Meter--sent to manufacturer for repair

2) Residual chlorine analyzers--chemical feed "star wheels" had to be replaced a number of times due to defective parts

3) Conductivity module in the Schneider Robot Monitor--replaced operational amplifier.

During a considerable portion of the monitoring program, the chloride module of the Schneider Robot Monitor did not function properly. It was difficult to calibrate and when calibrated it would almost immediately begin to slowly drift out of calibration. Late in the monitoring program, after numerous attempts by the MWD staff to adjust and repair the unit, it was sent to the manufacturer for repair. Considerable chloride data was lost during the repair period; however, the daily samples that were taken and titrated with silver nitrate provided sufficient chloride data.

It should be pointed out that in none of the above described problems could the failure be attributed to the fact that the instrument was installed in the mobile laboratory and thus was subjected to some rather rough treatment during transit between locations.

SECTION 7

RESULTS AND DISCUSSION

GENERAL

A tremendous amount of data on water quality parameters that could be measured by the monitoring systems on the EPA mobile laboratory was collected during this study. Without the capabilities of the on-board computer-recorder and the back-up data processing capabilities at MWD's Data Processing Center, meaningful data reduction for evaluation of the results would have been a herculean task, if not impossible.

An understanding of the chemical composition of the source waters imported by MWD and the ensuing quality after blending and filtration is needed to set the stage for discussion of the results of the distribution system monitoring program. Table 4 shows the average chemical analysis for the major constituents in the Colorado River and State Project source waters, as determined at MWD's central laboratory, during this investigation. Typical chemical analyses of the imported surface waters after blending and treatment at the filtration plants are presented in Table 5. Except for transient differences in blending ratios, the Diemer filtration plant effluent is similar to the Weymouth plant filtered water.

Typical chemical analyses of the groundwaters tested during this study are shown in Table 6. These analyses were obtained from the cooperating water utilities where field monitoring was performed.

The range in quality characteristics for all these waters was:

	Units	Minimum		Maximum
Electrical Conductivity	µmhos/cm	370	-	1195
Total Dissolved Solids	mg/L	240	-	760
Total Hardness	mg/L	61	-	325
Total Alkalinity	mg/L	86	-	214
Sulfate	mg/L	17	-	290
Chloride	mg/L	16	-	106
pH		7.4	-	8.4
Carbon Dioxide	mg/L	1.6	-	11
Dissolved Oxygen	mg/L	2.5	-	11.6

The total dissolved solids content and alkalinity of these waters varied from intermediate to high and they would be classed as moderately hard to very hard waters. These characteristics of the waters studied should be kept in

TABLE 4. CHEMICAL ANALYSIS OF MWD SOURCE WATERS
AVERAGES FROM JANUARY 1977 TO JUNE 1978

		Source of Water		
		Colorado River	State Project	
Constituent	Symbols and Units	Lake Mathews	Lake Silverwood	Castaic Lake
SILICA	SiO_2 mg/L	9.9	11.5	13.8
CALCIUM	Ca mg/L	80	27	42
MAGNESIUM	Mg mg/L	30.5	16.0	16.0
SODIUM	Na mg/L	104	73	45
POTASSIUM	K mg/L	4.6	3.7	2.6
CARBONATE	CO_3 mg/L	0	1.4	0.3
BICARBONATE	HCO_3 mg/L	153	103	120
SULFATE	SO_4 mg/L	290	56	90
CHLORIDE	Cl mg/L	92	106	53
NITRATE	NO_3 mg/L	0.2	0.6	0.5
FLUORIDE	F mg/L	0.31	0.1	0.22
BORON	B mg/L	0.13	0.18	0.19
TOTAL DISSOLVED SOLIDS*	mg/L	688	347	324
TOTAL HARDNESS AS $CaCO_3$	mg/L	325	133	171
TOTAL ALKALINITY AS $CaCO_3$	mg/L	125	86	99
FREE CARBON DIOXIDE (Calc.)	CO_2 mg/L	1.4	1.0	2.7
HYDROGEN ION CONCENTRATION	pH	8.27	8.27	7.87
ELECTRICAL CONDUCTIVITY	µmho/cm @25°C	1060	618	544
TURBIDITY	TU	1.6	3.2	2.5
TEMPERATURE	°C	17	14	13

* TDS determined by summation by method in Ref. 7, p. 146-147.

mind during the ensuing discussion. Moreover, the concentration values for some of the constituents will be useful in computing corrosion indices (10).

Table 7 presents the mean values for the water quality parameters related to corrosion and stability monitored by the mobile laboratory. The waters tested are divided into groups based on the major source or type of water. The replicate tests within each group are listed chronologically together with site location. Within each group the locations where zinc phosphate was added to stabilize the water and mitigate corrosivity are

TABLE 5. TYPICAL CHEMICAL ANALYSIS OF MWD FILTERED WATERS -- MONTHLY COMPOSITE OF DAILY SAMPLES

CONSTITUENT	SYMBOLS AND UNITS	April 1977		April 1978		
		Colorado River Water	State Project Water	Colorado River Water	State Project Water	CRW/SPW Blend
		Weymouth Filtration Plant	Jensen Filtration Plant	Skinner Filtration Plant	Jensen Filtration Plant	Weymouth Filtration Plant
SILICA	SiO_2 mg/L	10.2	13.2	9.0	14.5	12.3
CALCIUM	Ca mg/L	83	36	77	45	56
MAGNESIUM	Mg mg/L	30.5	14.5	28.5	16.5	22
SODIUM	Na mg/L	108	43	100	52	79
POTASSIUM	K mg/L	4.7	2.2	4.5	3.3	3.9
CARBONATE	CO_3 mg/L	0	1	0	0	0
BICARBONATE	HCO_3 mg/L	154	110	151	118	120
SULFATE	SO_4 mg/L	299	76	274	107	189
CHLORIDE	Cl mg/L	92	52	88	60	79
NITRATE	NO_3 mg/L	0.4	0.2	0.1	0.2	0.2
FLUORIDE	F mg/L	0.34	0.16	0.32	0.32	0.24
BORON	B mg/L	0.12	0.22	0.10	0.18	0.10
TOTAL DISSOLVED SOLIDS	mg/L	705	293	657	358	502
TOTAL HARDNESS AS $CaCO_3$	mg/L	333	150	310	180	230
TOTAL ALKALINITY AS $CaCO_3$	mg/L	126	92	124	97	98
FREE CARBON DIOXIDE (Calc.)	CO_2 mg/L	2	0.7	2	2	1
HYDROGEN ION CONCENTRATION	pH	8.15	8.4	8.15	8.03	8.15
ELECTRICAL CONDUCTIVITY	µmho/cm @25°C	1090	500	1030	600	820
TURBIDITY	TU	0.2	0.3	0.2	0.2	0.2
TEMPERATURE	°C	15.5	14.5	16.5	12	15.5
PERCENT STATE PROJECT WATER		0	100	0	100	35-40

TABLE 6. TYPICAL CHEMICAL ANALYSIS OF GROUND WATERS USED DURING STUDY

CONSTITUENT	SYMBOLS AND UNITS	Pasadena Villa Well 9-6-7[illegible]	Orange Well#14 12-13-76	Anaheim Wells 5-31-77		Long Beach Well Water Blend Filtered 10-3-77	Burbank Well #11 3-20-78	Alhambra Wells San Gabriel Basin Average Values
				#27	#28			
SILICA	SiO_2 mg/L	21.5	20	12	11.0	21.4	26.5	29
CALCIUM	Ca mg/L	26	73	83.2	84	21.7	66	37
MAGNESIUM	Mg mg/L	6.8	13.9	26	23.8	1.7	16.5	13.3
SODIUM	Na mg/L	52	42	96	90	62	33	33
POTASSIUM	K mg/L	--	2.8	4.4	4.4	1.35	3.5	1.5
CARBONATE	CO_3 mg/L	0	0	0.5*	0.3*	0	0	--
BICARBONATE	HCO_3 mg/L	120	206	197	194	156	261	172
SULFATE	SO_4 mg/L	56	69	183	185	17.3	53	22.1
CHLORIDE	Cl mg/L	16	52	99	98	35.2	18	28.1
NITRATE	NO_3 mg/L	18.3	4.2	15.7	15.1	0.27	9.6	23.1
FLUORIDE	F mg/L	2.4	0.4	0.7	0.8	0.5	0.47	0.68
BORON	B mg/L	--	0.19	0.24	0.22	--	--	--
TOTAL DISSOLVED SOLIDS	mg/L	259	380	619	610	240	357	274
TOTAL HARDNESS AS $CaCO_3$	mg/L	94	240	310	302	61.2	233	148
TOTAL ALKALINITY AS $CaCO_3$	mg/L	98	169	161	160	128	214	141
FREE CARBON DIOXIDE (Calc.)	CO_2 mg/L	2.0	8.6	8.2	11	2.7	6.9	5.7
HYDROGEN ION CONCENTRATION	pH	8.0	7.6	7.57	7.47	8.02	7.8	7.7
ELECTRICAL CONDUCTIVITY	µmho/cm @25°C	410	650	975	975	413	570	--
TURBIDITY	TU	--	--	0.02	0.02	0.86	0.14	--
TEMPERATURE	°C	22	--	14.2	15.2	--	--	--

* Carbonate values calculated from equilibrium relationships-from nomograph in Ref. 9, p. 296.

TABLE 7. SUMMARY OF WATER QUALITY DATA FOR FIELD MONITORING STATIONS

Water Type	Loc. No.	Temp °C	D.O. mg/L	EC micro-mho/cm @25°C	Ca^{++} mg/L	T.H. mg/L as $CaCO_3$	Alk. mg/L as $CaCO_3$	pH	Free CO_2 mg/L (Calc)	pH_s (nomo-graph)	Langelier Index	Ryzner Index	CCDT Slope μA/min	Comments
SPW	2	15	10.7	490	35	146	89	7.7	3.6	8.2	-0.5	8.7	46.0	$Zn_3(PO_4)_2$Added
SPW	3a	13	10.7	490	38	144	94	8.3	1.1	8.2	0.1	8.1	0.22	
SPW	13	17	6.3	540	44	174	111	7.9	2.3	8.05	-0.15	8.2	0.24	
SPW	22	13	10.0	604	44	172	96	7.9	2.7	8.18	-0.28	8.46	0.42	
CRW	5	15	10.9	1117	82	332	124	8.1	2.0	7.9	0.2	7.7	2.16	
CRW	9	21	7.8	1130	82	337	124	7.8	3.6	7.79	0.01	7.78	3.0	No pH Adjustment
CRW	10a	21	6.3	1110	82	330	127	8.1	1.9	7.78	0.32	7.46	3.17	
CRW	20	15	10.4	1060	80	326	120	8.2	1.5	7.92	0.28	7.64	57.0	$Zn_3(PO_4)_2$ Added
CRW	21	14	10.2	1090	82	325	120	8.2	1.6	7.95	0.25	7.7	2.0	
CRW/SPW	1a	13	10.7	760	52	218	117	8.0	2.4	8.08	-0.08	8.16	2.29	
CRW/SPW	3b	13	11.3	840	56	230	102	7.7	2.5	8.1	-0.4	8.5	2.5	
CRW/SPW	4	16	11.6	795	55	222	98	7.5	6.2	8.08	-0.58	8.66	58.0	$Zn_3(PO_4)_2$ Added
CRW/SPW	14	20	9.2	750	58	236	117	8.2	1.4	7.9	0.3	7.6	0.9	
CRW/SPW	23	15	9.8	950	67	266	109	8.1	1.8	8.0	0.1	7.9	1.39	
CRW/SPW	26	16	9.5	790	57	228	96	8.1	1.6	8.06	0.04	8.02	--	
CRW/SPW	27	18	9.5	565	39	176	77	7.8	2.5	8.22	-0.42	8.64	1.2	
CRW/SPW	28	20	9.0	530	40	159	78	7.4	6.0	8.12	-0.72	8.84	54.0	$Zn_3(PO_4)_2$Added
CRW/SPW	35	25	6.2	713	45	190	85	7.5	4.8	8.03	-0.52	8.56	0.6	No pH Adjustment
CRW/SPW	36	25	7.9	880	61	244	114	7.9	2.5	7.88	0.02	7.86	1.3	
GW	8	21	7.5	690	75	256	163	7.3	16.0	7.6	-0.3	7.9	1.5	
GW	12	17	4.4	980	86	329	192	7.6	9.5	7.6	0.0	7.6	0.33	
GW	16	27	2.5	370	20	61	132	7.4	9.4	8.05	-0.65	8.7	--	
GW	24	19	7.6	510	69	237	214	7.4	17.0	7.52	-0.12	7.64	--	
CRW/GW	7	19	7.3	900	82	280	170	7.7	6.5	7.63	0.07	7.56	2.58	
CRW/GW	10b	22	6.6	1195	117	406	215	7.3	19.0	7.35	-0.05	7.40	--	
CRW/GW	11a	25	5.8	980	80	312	122	7.4	8.5	7.72	-0.32	8.04	2.8	
CRW/GW	11b	22	7.6	980	117	395	210	7.7	7.5	7.30	0.40	6.9	1.5	
CRW/GW	15	24	3.5	554	38	137	128	7.4	9.4	7.90	-0.5	8.4	27.0	$Zn_3(PO_4)_2$ Added
CRW/GW	17	23	3.5	620	42	150	126	7.5	7.4	7.93	-0.43	8.36	--	
CRW/GW	18	24	4.0	570	38	144	129	7.4	9.4	7.90	-0.5	8.4	--	
CRW/GW	19	17	10.4	950	78	326	120	7.9	3.1	7.85	0.05	7.8	61.0	$Zn_3(PO_4)_2$ Added
CRW/SPW/GW	1b	18	9.0	600	62	240	150	7.5	10.0	7.75	-0.25	8.0	5.0	
CRW/SPW/GW	25a	17	9.7	903	66	262	110	8.1	1.7	7.97	0.13	7.84	--	
CRW/SPW/GW	25b	19	7.2	571	70	240	215	7.5	14.0	7.52	-0.02	7.54	17.8	
CRW/SPW/GW	29a	22	9.0	675	53	202	91	7.9	2.1	7.97	-0.07	8.04	1.4	
CRW/SPW/GW	29b	20	8.3	830	84	280	146	7.6	7.2	7.70	-0.10	7.8	3.8	

TABLE 8. CORROSION RATES FOR MILD STEEL, ZINC, AND COPPER FROM FIELD MONITORING STATIONS (7TH DAY CORROSION RATES)

Location No.	Water Type	Mild Steel Anodic mils/yr	Mild Steel Cathodic mils/yr	Zinc Anodic mils/yr	Zinc Cathodic mils/yr	Copper Anodic mils/yr	Copper Cathodic mils/yr	CCDT μA/min	Comments
4	CRW/SPW	8.4	7.2	3.7	3.0	2.0	1.2	58	$Zn_3(PO_4)_2$ Added
5	CRW	8.0	8.0	2.5	2.2	2.5	2.0	.16	
7	CRW/GW	4.8	4.0	2.1	2.2	0.5	0.5	2.58	
8	GW	9.1	8.8	3.4	3.4	0.5	0.5	1.5	
9	Anaheim Treat.CRW	7.0	6.0	4.4	4.3	1.5	1.2	3.0	No pH Adj.
10a	CRW/GW	9.2	8.3	2.8	2.8	1.3	1.0	3.17	
10b	CRW/GW	8.9	7.8	2.0	1.7	1.7	1.3	----	
20	CRW	5.7	5.0	0.6	0.6	1.1	0.6	57	$Zn_3(PO_4)_2$ Added
21	CRW	6.6	6.2	2.9	2.3	1.8	1.3	2	
22	SPW	7.1	6.6	3.8	3.1	0.8	0.6	0.42	
23	CRW/SPW	4.0	3.7	2.9	2.4	1.4	1.1	1.39	
24	GW	4.6	4.6	2.6	1.8	0.8	0.8	-----	
25a	CRW/SPW/GW	6.0	5.3	6.6	5.0	0.4	0.3	-----	
25b	CRW/SPW/GW	4.9	4.6	2.2	1.8	0.8	0.5	17.8	
26	CRW/SPW	6.5	6.0	2.0	1.5	1.1	0.8	-----	
27	CRW/SPW	7.4	6.9	4.9	4.3	1.3	1.0	0.8	
28	CRW/SPW	9.0	8.1	5.3	4.4	0.9	0.7	54	$Zn_3(PO_4)_2$ Added

(Continued)

TABLE 8. (Continued)

Location No.	Water Type	Mild Steel Anodic mils/yr	Mild Steel Cathodic mils/yr	Zinc Anodic mils/yr	Zinc Cathodic mils/yr	Copper Anodic mils/yr	Copper Cathodic mils/yr	CCDT μA/min	Comments
29a	CRW/SPW/GW	8.0	7.3	3.6	2.9	0.9	0.8	1.4	
29b	CRW/SPW/GW	8.4	7.7	2.1	1.8	1.2	1.0	3.8	
30	CRW/SPW	7.8	6.9	1.9	1.5	1.1	0.8	-----	No pH Adj.
31	CRW/SPW	7.4	7.0	2.7	2.1	1.1	0.8	-----	No pH Adj.
34	CRW/SPW	10.4	9.4	4.1	3.2	1.3	0.9	-----	No pH Adj.
36	CRW/SPW	8.7	7.7	2.2	1.6	0.6	0.6	1.3	
	Locations 11a through 19 had the ground loop in the corrosion meter circuit								
11a	CRW/GW	9.1	10.0	4.9	3.7	-	-	2.8	
11b	CRW/GW	7.7	9.0	1.7	1.6	-	-	1.5	
12	GW	7.6	7.3	5.9	2.3	-	-	0.33	
13	SPW	6.1	6.4	3.4	1.8	-	-	0.24	
14	CRW/SPW	5.0	4.9	2.8	2.3	-	-	0.9	
15	CRW/GW	7.0	7.4	2.8	1.2	-	-	27	$Zn_3(PO_4)_2$ Added
16	GW	7.0	6.9	4.2	3.7	-	-	-----	
17	CRW/GW	7.5	7.6	4.7	2.7	-	-	-----	
18	CRW/GW	8.3	8.3	5.5	3.6	-	-	-----	
19	CRW/GW	6.8	8.3	4.2	1.1	-	-	61	$Zn_3(PO_4)_2$ Added

noted in the far-right column marked "comments". The time intervals between repeated tests on a particular water can be ascertained by reference to location numbers in Table 2.

In addition to summarizing the monitoring data, Table 7 shows calculated values for free carbon dioxide, pH at calcium carbonate saturation (pH_s), Langelier index, Ryzner index and the slope for the calcium carbonate deposition test (CCDT) in microamperes/minute. Correlations between these indices on the tendency for protective film formation will be discussed later.

Table 8 indicates the instantaneous corrosion rates for mild steel, zinc, and copper as measured by the current required to polarize the test electrode ten millivolts anodic or cathodic to the reference electrode. The readout is calibrated in mils per year of surface corrosion.

Except as noted, the corrosion rate measurements reported here represent the average rate for the seventh day of exposure to each water. As discussed in Section 6, these data do not represent the minimum corrosion rate that may be expected, particularly for mild steel and zinc, but it was the time selected for comparison of waters when the daily rate of change was relatively low.

Tables 9, 10, and 11 indicate the gradual decrease in the instantaneous corrosion rate after longer exposure periods and provide support for the rationale of selecting the seventh day corrosion rate for comparison of the different waters. It appears that the corrosion rate for copper, Table 11, approaches a steady state more quickly than for mild steel and zinc. Moreover, the copper corrosion rate was not affected adversely by changes in the sample flow velocity past the electrode surface. In contrast, the mild steel and zinc electrodes indicated that the measured corrosion rates fell sharply when flows decreased to less than 300 ml/min and increased markedly immediately after adjusting the flow upward to the normal rate, see La Verne Test 5 in Tables 9 and 10. This response was most noticeable when low velocity flows occurred during the first week of exposure after cleaning the electrodes. As explained in Section 4, the problem of variable flow rates to the corrosion rate cell was overcome by installing a constant head device on the feed line.

Beyond the effects of low sample flow on the mild steel and zinc corrosion rates, the accidental ground loop introduced into the corrosion rate meter circuit, which was discussed in Section 6, produced anomalous readouts from the copper electrode in both the anodic and cathodic modes at Locations 11 to 19. These data are omitted from Table 8. The ground loop circuit also affected the corrosion rate measurements at Locations 11 to 19 for mild steel and zinc. However, the bias on readings was less marked and the data are presented for comparison within the group.

The trace metal content of the water was determined on grab samples taken at each field monitoring location, and the average values are presented in Table 12. Since a continuous flow condition was required to operate the corrosion rate meter and to obtain data on other parameters,

TABLE 9. COMPARISON OF LONG TERM CORROSION TESTS
MILD STEEL ANODIC CORROSION RATE (MILS/YEAR)

Time Days	La Verne Test 1	La Verne Test 2,3,4	La Verne Test 5	Skinner Filt.Plant	Foothill MWD
	No pH Adjustment			pH Adjustment	
0	18.0	18.2	18.0	15.7	15.8
0.5	14.7	14.5	14.7	13.7	11.0
1.0	13.5	13.1	11.7	11.7	10.4
1.5	11.8	12.5	9.7	----	9.4
2	11.2	11.7	8.8	----	8.5
3	10.0	10.0	8.0	10.0	7.6
4	9.0	8.7	7.5	9.3	6.8
5	8.0	7.8	*-----* 10.8	9.2	6.5
6	7.7	7.5	10.5	8.9	6.4
7	7.7	7.5	10.3	8.6	6.5
8	7.7	7.5	9.8	8.5	
9	7.7	---	9.7	8.3	
10	7.7	---	9.2	8.1	
11	7.7	---	8.7	7.9	
12	7.4	---	8.6	7.7	
13	7.3	---	7.8	7.4	
14		---	---	7.3	
15		3-----3 6.8	7.4	---	
16		6.4	7.6	6.9	
17		6.4	7.4	6.6	
18		4-----4 6.2	7.2	6.5	
19		6.0	6.7	6.3	
20		6.1		6.2	
21		5-----5 6.1		6.0	
22		5.8		5.8	
25		6-----6 5.5			
26		5.0			
27		4.7			
28		7-----7 4.2			
30		4.0			
32		5-----5 3.7			
35		3.5			
38		3.5			
41		3.5			
48		3.5			
53		3.6			

---- Flow Adjustment
n----n Change in flow rate to $n \times 10^2$ ml/min (standard flow is 500 ml/min)

TABLE 10. COMPARISON OF LONG TERM CORROSION TESTS ZINC ANODIC CORROSION RATE (MILS/YEAR)

Time Days	La Verne Test 1	La Verne Test 2,3,4	La Verne Test 5	Skinner Filt.Plant	Foothill MWD
	No pH Adjustment			pH Adjustment	
0	15.0	19.0	20.3	21.5	13.6
0.5	13.5	14.5	11.7	12.5	5.8
1.0	12.5	12.0	9.2	6.0	3.8
1.5	11.6	10.3	7.0	---	3.0
2	8.7	9.0	5.2	---	2.8
3	3.8	4.7	2.8	2.3	2.3
4	1.7	2.8	1.6	2.1	2.5
5	1.4	1.8	*----* 5.4	2.2	2.3
6	1.7	2.4	4.3	2.2	2.2
7	2.6	2.7	4.0	2.2	1.8
8	1.4	2.3	3.7	2.2	
9	2.3	---	3.6	2.0	
10	2.7	---	3.3	2.0	
11	3.2	---	3.0	1.8	
12	2.8	---	2.8	1.6	
13	3.2	---	3.0	1.7	
14		---	---	1.7	
15		3----3 3.2	2.7	---	
16		2.7	2.7	1.7	
17		2.6	2.7	1.8	
18		4----4 2.5	2.7	1.8	
19		2.0	2.9	1.7	
20		2.2		1.6	
21		5----5 1.9		1.7	
22		2.0		1.6	
25		6----6 1.7			
26		1.6			
27		1.4			
28		7----7 1.3			
30		1.2			
32		5----5 1.2			
35		1.3			
38		1.2			
41		0.8			
48		0.6			
53		0.5			

---- Flow Adjustment
n----n Change in flow rate to nx10^2 ml/min (standard flow is 500 ml/min)

TABLE 11. COMPARISON OF LONG TERM CORROSION TESTS
COPPER ANODIC CORROSION RATES (MILS/YEAR)

Time Days	La Verne Test 1	La Verne Test 2,3,4	La Verne Test 5	Skinner Filt.Plant	Foothill MWD
	No pH Adjustment			pH Adjustment	
0	3.1	3.7	4.5	2.2	2.3
0.5	1.8	1.8	1.3	1.6	1.4
1.0	1.5	1.6	1.1	1.5	1.3
1.5	1.3	1.4	1.0	---	1.4
2	1.3	1.2	0.8	---	1.0
3	1.1	1.1	0.8	1.1	1.0
4	1.1	1.1	0.8	0.9	1.2
5	1.1	1.2	*-----* 0.9	0.7	1.0
6	1.1	1.1	1.2	0.7	1.1
7	1.1	1.1	1.2	0.6	1.0
8	1.2	1.1	1.2	0.6	
9	1.2	---	1.1	0.6	
10	1.1	---	1.1	0.6	
11	1.2	---	1.2	0.5	
12	1.1	---	1.1	0.5	
13	1.1	---	1.1	0.5	
14		---	---	0.5	
15		3-----3 0.5	1.4	---	
16		1.0	1.3	0.5	
17		0.9	1.3	0.5	
18		4-----4 0.9	1.3	0.5	
19		0.9	1.4	0.5	
20		0.9		0.5	
21		5-----5 0.9		0.6	
22		0.9		0.5	
25		6-----6 0.7			
26		0.7			
27		0.6			
28		7-----7 0.5			
30		0.4			
32		5-----5 0.3			
35		0.3			
38		0.3			
41		0.4			
48		0.3			
53		0.3			

----- Flow Adjustment
n-----n Change in flow rate to nx10^2 ml/min (standard flow 500 ml/min)

TABLE 12. TRACE METAL LEVELS AT FIELD MONITORING STATIONS

Location No.	Water Type	Average Values in mg/L						Number of Samples
		Cd	Pb	Cu	Zn	Fe	Mn	
1	CRW/SPW/GW	-	-	0.003	0.01	0.03	-	7
2	SPW+Zn	-	-	0.007	1.10	-	-	4
3a	SPW	-	-	0.007	0.01	-	-	5
3b	CRW/SPW	ND	ND	0.032	0.02	0.01	ND	4
4	CRW/SPW+Zn	0.0001	ND	0.027	1.14	0.02	ND	7
5	CRW	ND	ND	0.005	ND	0.02	ND	1
6	CRW	ND	ND	0.013	0.01	0.02	ND	3
7	CRW/GW	ND	ND	0.006	0.01	0.02	ND	2
8	GW	ND	0.0001	0.004	0.02	0.01	ND	2
9	Anaheim CRW	ND	ND	0.085	0.01	0.01	ND	2
10	Met CRW	ND	ND	0.100	ND	ND	ND	2
11	CRW/GW	ND	ND	0.100	0.03	0.02	ND	2
12	GW	ND	0.0007	0.007	0.06	0.02	ND	2
13	SPW	ND	0.0004	0.006	0.02	0.01	ND	2
14	SPW/CRW	ND	0.0003	ND	0.02	0.01	ND	2
15	CRW/GW+Zn	ND	ND	ND	0.66	0.02	ND	2
16	GW	ND	ND	ND	0.03	0.02	ND	2
17	CRW/GW	ND	ND	ND	0.12	0.05	ND	2
18	CRW/GW	0.0001	ND	ND	0.03	0.03	ND	2
19	CRW/GW+Zn	ND	0.0004	ND	1.46	0.03	ND	2
20	CRW+Zn	ND	ND	ND	0.79	0.02	ND	3
21	CRW	ND	0.0002	ND	0.06	0.04	ND	2
22	SPW	ND	0.0002	ND	0.01	0.02	ND	2
23	CRW/SPW	ND	0.0001	ND	ND	ND	ND	2
24	GW	ND	0.0004	ND	ND	ND	ND	2
25	CRW/SPW/GW	ND	0.0005	ND	0.33	ND	ND	2
26	CRW/SPW	ND	0.0003	ND	0.03	0.02	-	2
27	CRW/SPW	0.0003	ND	0.02	ND	0.05	ND	2
28	CRW/SPW+Zn	0.0002	ND	0.02	0.95	0.04	ND	2
29	CRW/SPW/GW	ND	0.0002	ND	ND	0.06	ND	2
ND = None Detected at detection limits:		0.0001	0.0001	0.01	0.01	0.01	0.01	

metal uptake after long residence times or "no flow" conditions could not be monitored on board the mobile laboratory. At the outset, several grab samples were taken at each field location for analysis at MWD's central laboratory at La Verne; but when the analytical results indicated that metal concentrations were below the detection limit in most cases the frequency of sampling was reduced.

The aforementioned tables summarize the massive amount of data collected into single mean values. For each parameter the value reported may represent an average of 100 to 3,000 sets of data for the tests performed aboard the mobile laboratory. In a dynamic water system, significant variations in water quality may occur due to blending and in-line mixing of water sources. The capability of the laboratory for detecting such changes will be brought out in greater detail as the results are discussed below.

INTERRELATIONS BETWEEN WATER QUALITY PARAMETERS

Larson (10), Ryder (11) and others have pointed out the strengths and weakness of the several accelerated tests, water quality parameters and indices used for comparing the stability and corrosivity of waters. In this water quality investigation, an attempt was made to develop and evaluate some of the correlations and interrelationships suggested by earlier workers. First, we will look for correlations based on the data obtained at all the locations monitored and then compare data illustrating specific water quality conditions, such as use of corrosion control chemicals.

Effect of pH on Corrosion Rates

Experience has taught water works personnel the value of pH control for corrosion protection, and the principles of the saturation index as derived by Langelier (12) has been useful as a guideline for pH control for many years. Larson and Buswell (13) pointed out some limitations on the interpretation of Langelier's index as a measure of calcium carbonate deposition capacity for corrosion control. Using the field water quality data obtained in this study, the Langelier saturation index was computed, Table 7. Then, the anodic linear polarization measurement of corrosion rates on the seventh day was plotted against this saturation index for the waters tested in Figure 12.

As would be expected when the saturation index shifts from negative to positive, the linear polarization corrosion rate for mild steel and zinc decreased moderately. However, the corrosion rate measurements for copper did not show any adverse effect of lower pH and negative saturation values for the waters tested. The range of pH values was from 7.3 to 8.3, and the Langelier index varied from -0.72 to +0.32.

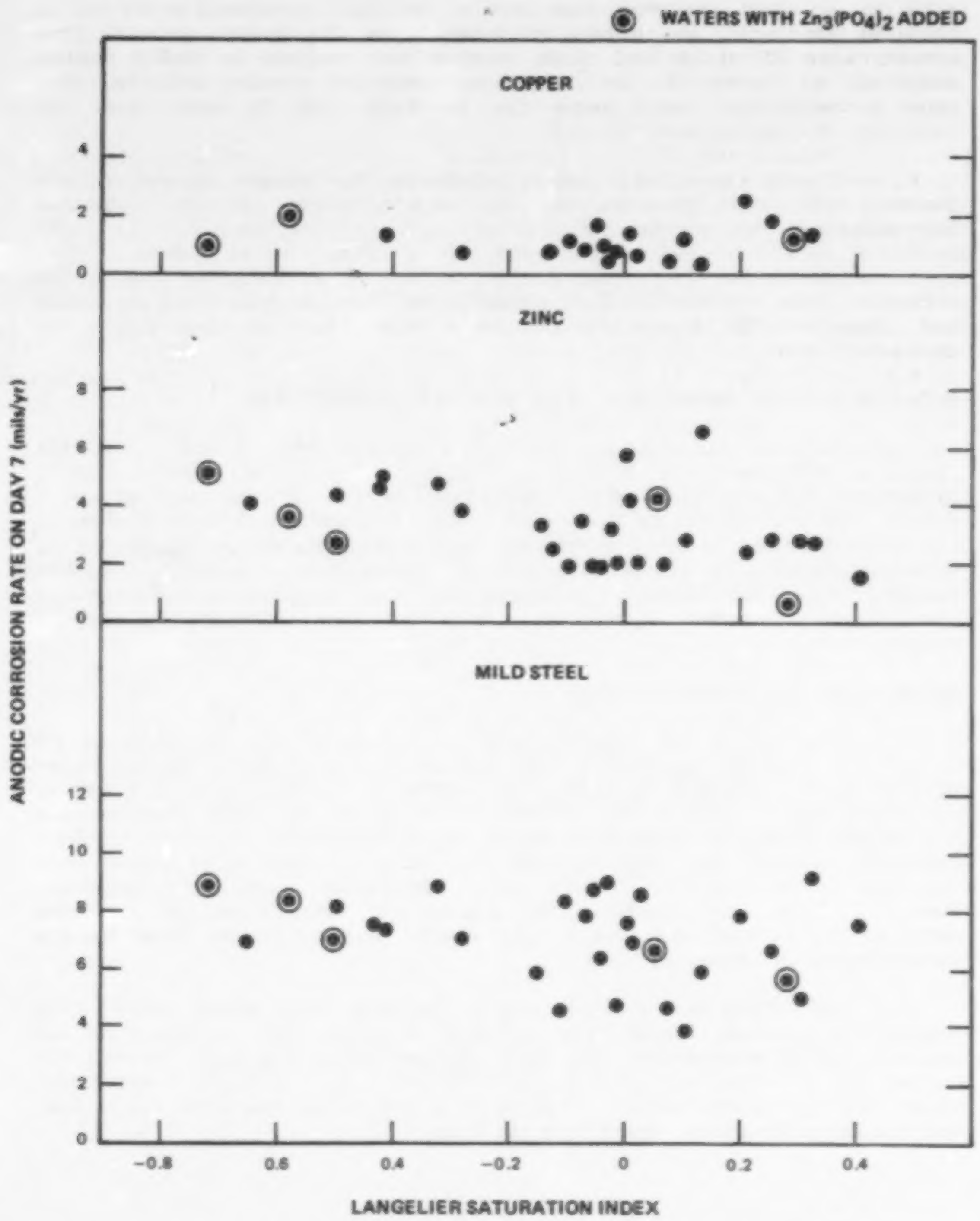


Figure 12. Corrosion rates for mild steel, zinc, and copper on day 7 vs. Langelier saturation index.

Another "stability index" was devised by Ryzner (14). It is equal to $2\ \mathrm{pH}_s - \mathrm{pH}$, an impirical value which places greater emphasis on the concentration of calcium and alkalinity as related to scale-forming characteristics of the water. Figure 13 shows anodic linear polarization corrosion rates on the seventh day plotted against the Ryzner stability index.

Waters with a stability index of ≤ 7.5 are scale-forming according to Ryzner, and waters with indices >7.5 are increasingly scale dissolving. Recently, Ryder (11) indicated that waters in the Seattle area were increasingly corrosive with values above 8.0.

It should be noted that there was a slight trend for higher corrosion rates for mild steel and zinc as the Ryzner index (RI) increased, but there was no sharp demarkation between scale-forming and scale-dissolving characteristics for these waters with RI values ranging from 6.9 to 8.8. As in Figure 12, the pH effect as measured by the Ryzner stability index showed no measurable difference in the corrosion rate of copper in these tests. The Ryzner index will be discussed again in relation to the calcium carbonate deposition test results.

Effect of Calcium Content on Corrosion Rates

The seventh day anodic linear polarization measurement of corrosion rates was plotted against the calcium content of these waters, ranging from 39 to 84 mg/L, in Figure 14. There is a slight trend toward lower corrosion rates as the calcium content increases. The scatter of points, however, suggests that other factors, such as, pH and alkalinity probably exert a more profound effect on corrosion rates than calcium as an independent parameter. Calcium levels may provide insight into the capacity of a water to deposit films which will be discussed in relation to the CCDT measurements.

Effect of Dissolved Minerals on Corrosion Rates

In this investigation, electrical conductivity was the parameter used to measure the variations in mineral content of the waters examined in the field. Conversion of conductivity measurements to the more familiar term, total dissolved solids (TDS) may be approximated by multiplying conductivity in micromhos/cm by 0.65 for the waters studied. More precise estimates for this conversion factor can be obtained for each blend of water tested by using conductivity and TDS values obtained by analysis of the waters before blending. These data are shown in Tables 5 and 6. The anodic polarization corrosion rates for mild steel, zinc, and copper are plotted against conductivity in Figure 15 for the waters studied.

Numerous studies (1,2,3,10) have suggested that a strong positive correlation may be expected between total dissolved solids or conductivity and corrosion rates. For the waters studied with conductivities ranging from 370 to 1195 micromhos/cm and TDS from 240 to 760 mg/L, there was no observable trend toward higher corrosion rates for mild steel and zinc as the conductivity increased. There was an indication of slightly higher corrosion rates for copper at higher conductivities. Whether this is related

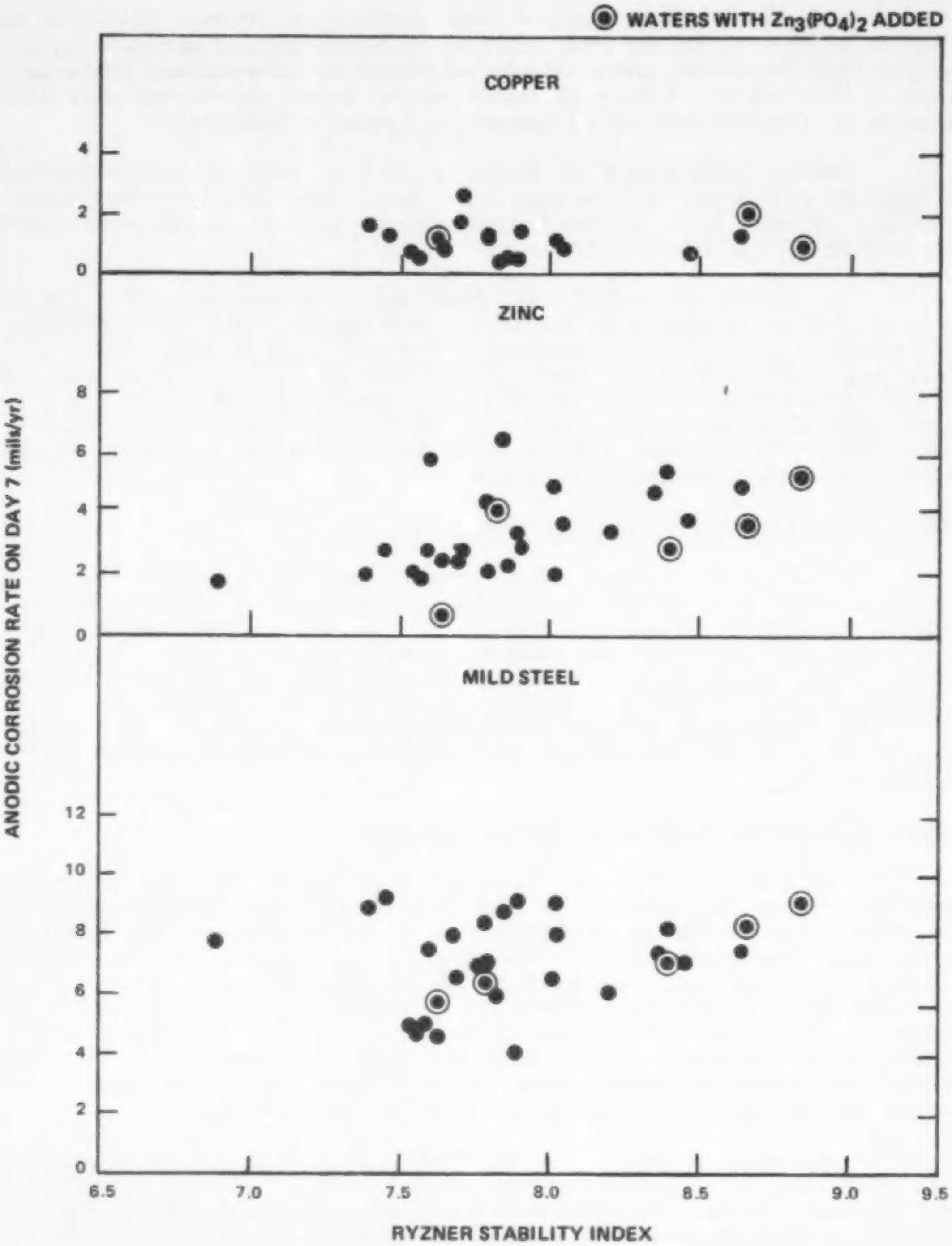


Figure 13. Corrosion rates for mild steel, zinc, and copper on day 7 vs. Ryzner stability index.

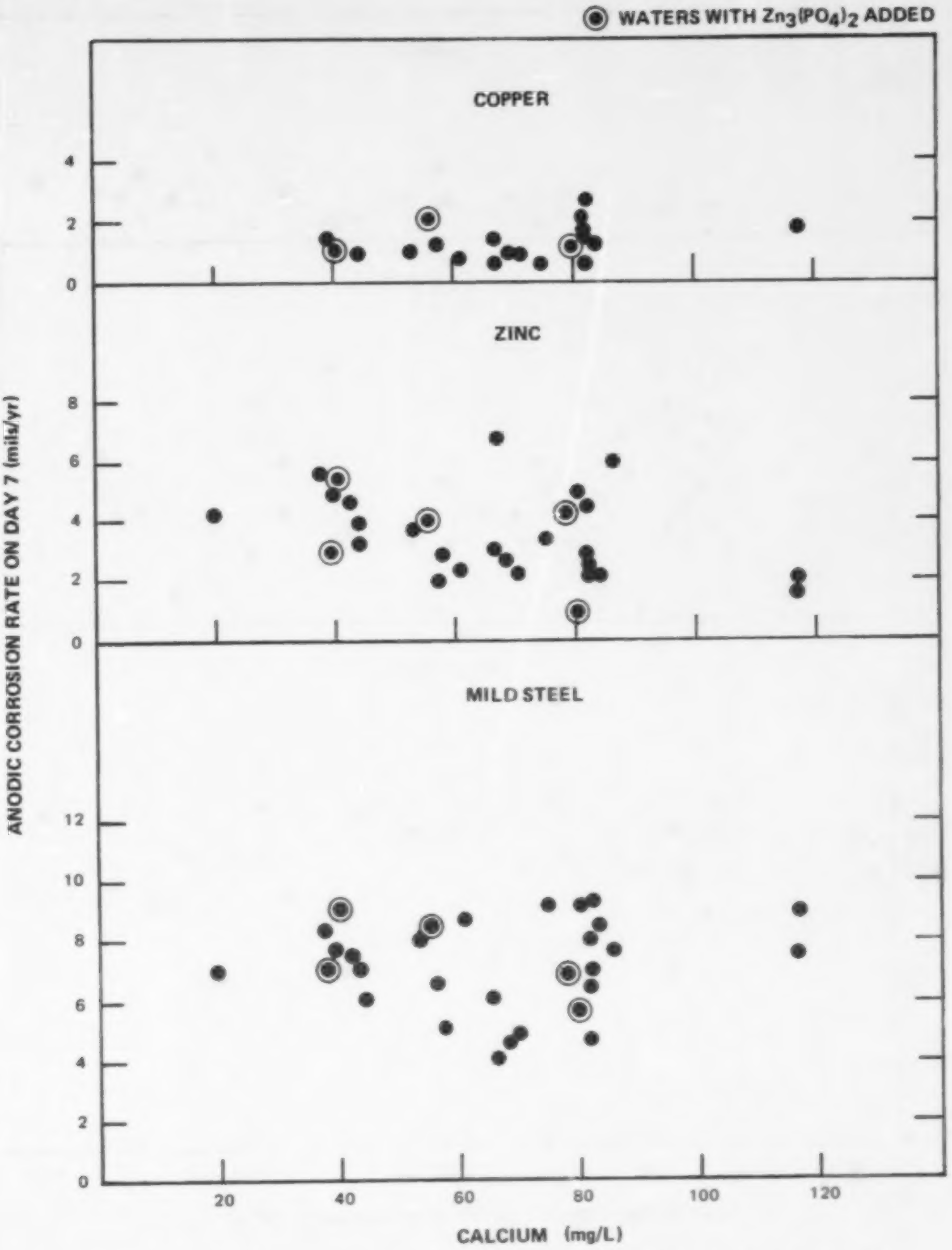


Figure 14. Corrosion rates for mild steel, zinc, and copper on day 7 vs. calcium content.

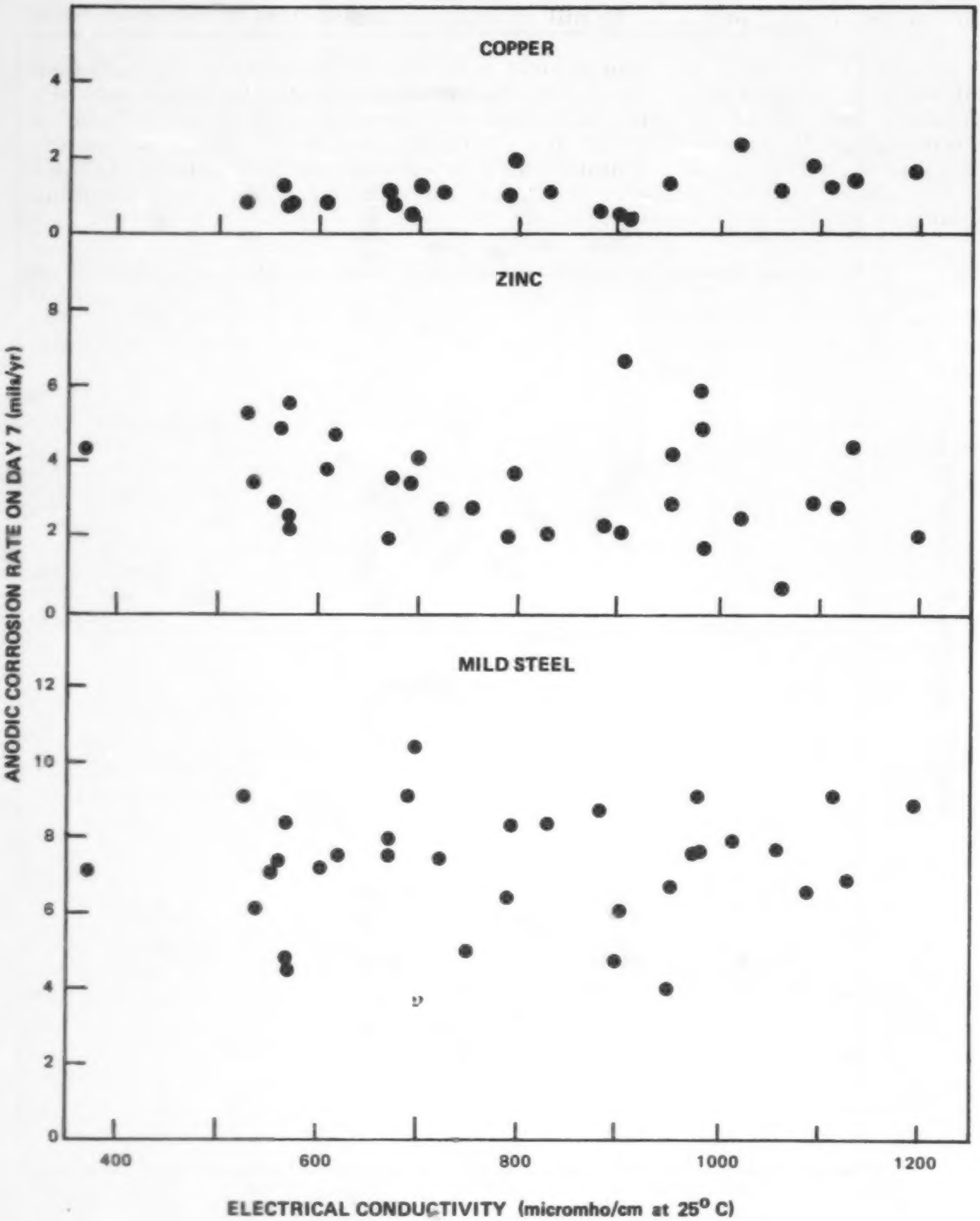


Figure 15. Corrosion rates for mild steel, zinc, and copper on day 7 vs. electrical conductivity.

to higher mineralization, per se, or due to a specific effect, such as, free carbon dioxide, pH or alkalinity will be explored later.

It should be pointed out that the instantaneous polarization corrosion rate determined by the mobile laboratory instrumentation does not measure the effect of mineralization on galvanic corrosion. This is associated with the contact of two different metals or alloys in water. Galvanic corrosion is most troublesome in household and institutional facilities where two or more dissimilar metals may be joined together in the plumbing system consisting of pipes, valves, and fittings.

Galvanic corrosion is generally increased when the difference in potential between two metals results in current flow and also by increased mineralization or conductivity of the water. However, it is one of the important corrosion mechanisms which could not be evaluated by the tests performed on board the mobile laboratory.

Despite these limitations, the corrosion rate instrument was sensitive enough to respond to diurnal changes in water quality where the variations in blending of source waters occurred at a single station. In effect, this resulted in paired sets of data where other variables remained constant. Even though the differences in corrosion rates were qualitative, the response to changes in water quality gave insight concerning the tendency of one water to be more or less aggressive than another to mild steel, zinc, or copper sensors. These observations will be discussed after presenting the data on the other parameters monitored on the mobile laboratory.

CALCIUM CARBONATE DEPOSITION TEST (CCDT)

For the waters analyzed during this project, the calcium carbonate deposition test was the most sensitive to differences in quality due to blending of source waters or diurnal changes in water characteristics. The rate of $CaCO_3$ film formation is determined from the slope of the linear portion of the current-time curve generated by a rotating gold disc electrode. The slope is then stated in microamperes per minute (μA/min).

The effect on CCDT of blending Colorado River water and State project water is shown in Figure 16. In this family of curves where lower calcium hardness is the most significant change in water quality characteristics, the CCDT slope progressively decreases. This indicates that the time required to form a protective film under the test conditions for the State project water with a calcium content of 44 mg/L was four times as long as for Colorado River water containing 85 mg/L of calcium. The significance of these differences in slope will be discussed later after further comparisons are made.

Alkalinity and pH are also basic water quality characteristics which affect the tendency for deposition or dissolution of $CaCO_3$ films. Recognizing the importance of maintaining pH near Langelier's saturation pH_s or higher, many utilities add caustic soda or lime as a final treatment step before the water enters the distribution system. Metropolitan adopted

Curve No.	Location No.	% Blend CRW/SPW	pH	Ca mg/L	Alk. mg/L	EC	CCDT Slope μA/min
1	5	100/0	8.1	85	125	1120	1.8
2	23	70/30	8.2	67	110	960	1.4
3	36	60/40	7.9	60	115	890	1.3
4	27	25/75	7.8	45	87	612	1.2
5	22	0/100	7.9	44	96	600	0.4

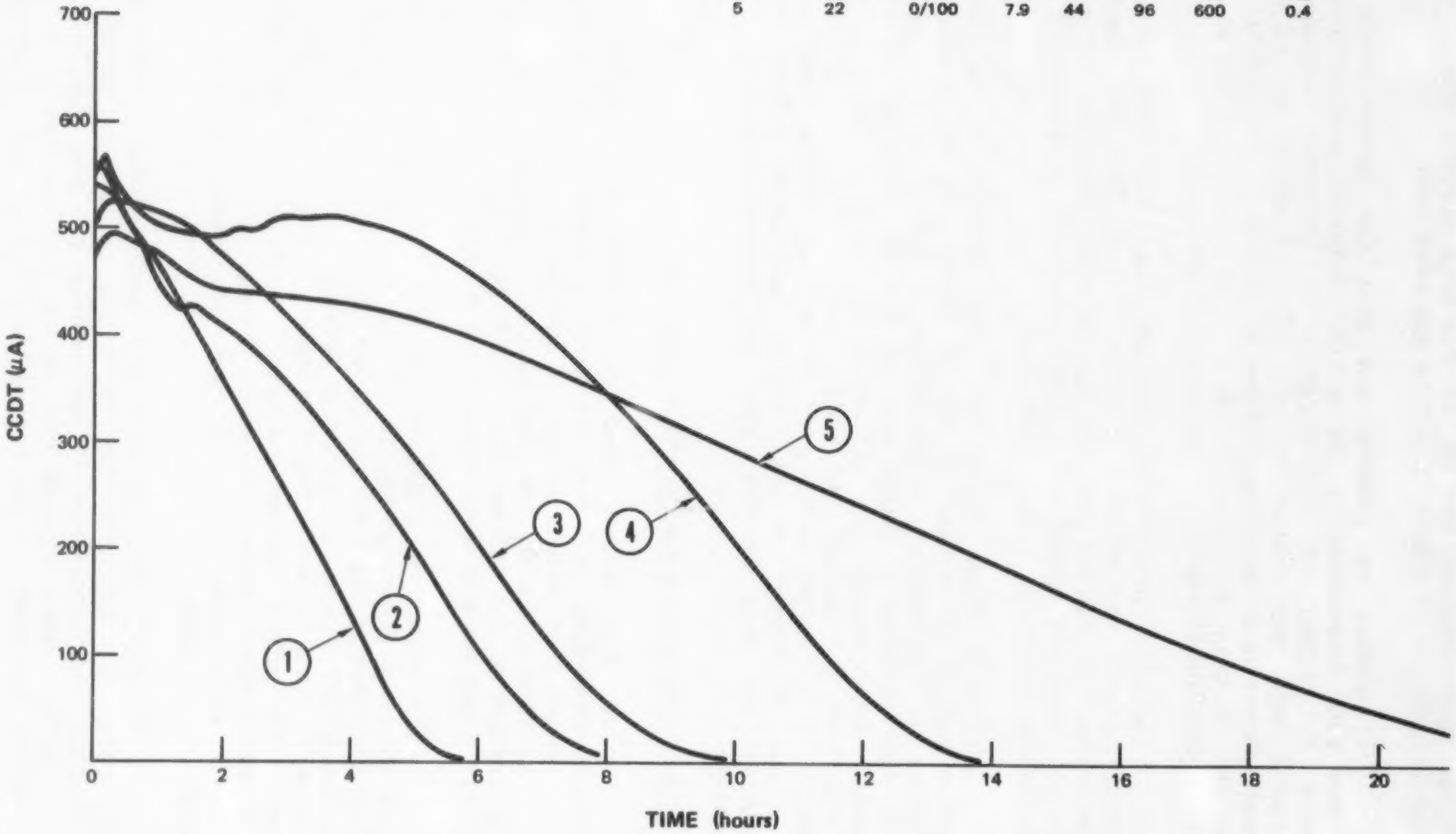


Figure 16. Effect of blending Colorado River water and State Project water on CCDT.

the practice of pH adjustment at each of its filtration plants from the outset, first using milk of lime and later using liquid caustic soda because of better control of dosages and increments in post-treatment turbidity.

Effect of pH Adjustment on CCDT

During the period when long-term corrosion tests reported in Tables 9 to 11 were being performed, the Weymouth plant filtered water was tested prior to pH adjustment. The slope of the CCDT curve for this water containing 45 percent CRW at Location 35 is shown in Figure 17. For comparison, the curves for two pH adjusted blends of water from the distribution system at Locations 27 and 36 are repeated from Figure 16. The quality of these waters containing 25 percent and 60 percent CRW, respectively bracketed the quality of filtered water tested before pH adjustment. The CCDT curve indicates that the film formation rate for filtered water was only one-half the rate, 0.6 μA/min. compared to 1.2 and 1.3, observed for the pH adjusted waters of similar quality. This difference in CCDT resulted from a pH adjustment of only 0.3 to 0.4 and changed the film forming characteristic from "slight" to "moderate" by the suggested criteria of McClelland and Mancy (5).

Effect of Alkalinity and Hardness on CCDT

After the CCDT unit was set up to cycle automatically and data could be collected for 24 hours each day, some interesting data showing the effect of water quality variations on calcium carbonate deposition were observed. At Location 29, groundwater was pumped into the distribution system daily after midnight. This intermittent pumping caused in-line mixing of higher amounts of groundwater with MWD water for 9 to 12 hours each day. Figure 18 shows CCDT data for the variations in water quality conditions when calcium hardness and total alkalinity changed significantly: Curve 1 indicates a CCDT value of 3.8 μA/min. when the greater percentage of ground water reached the mobile laboratory; Curve 2 for MWD water has a slope of 1.4; and Curve 3 represents a run that included a transition period where the quality changed after about 6 hours causing a distinct slope break to 6.7 μA/min.

From the above it appears that the CCDT is sensitive to changes in the quality of water being monitored and responds immediately to the change. Insufficient data were obtained after full automation of the CCDT system to determine the extent of a carryover effect when the electrode is partially covered by a $CaCO_3$ film from one water before exposure to another. At the very least, a qualitative comparison of waters can be observed. Moreover, when the residence time of each water in the distribution is long enough to complete a CCDT curve, such as, Curves 1 and 2 in Figure 18, good agreement on film formation rates was obtained on successive days.

Effect of Zinc Phosphate on CCDT and Corrosion Rates

Three water suppliers in MWD's service area were using zinc phosphate for corrosion control when field monitoring was being done on

Curve No.	Location No.	% Blend CRW/SPW	pH	CCDT Slope µA/min
1	36	60/40	7.9 Adjusted	1.3
2	27	25/75	7.8 Adjusted	1.2
3	35	45/55	7.5 Not Adjusted	0.6

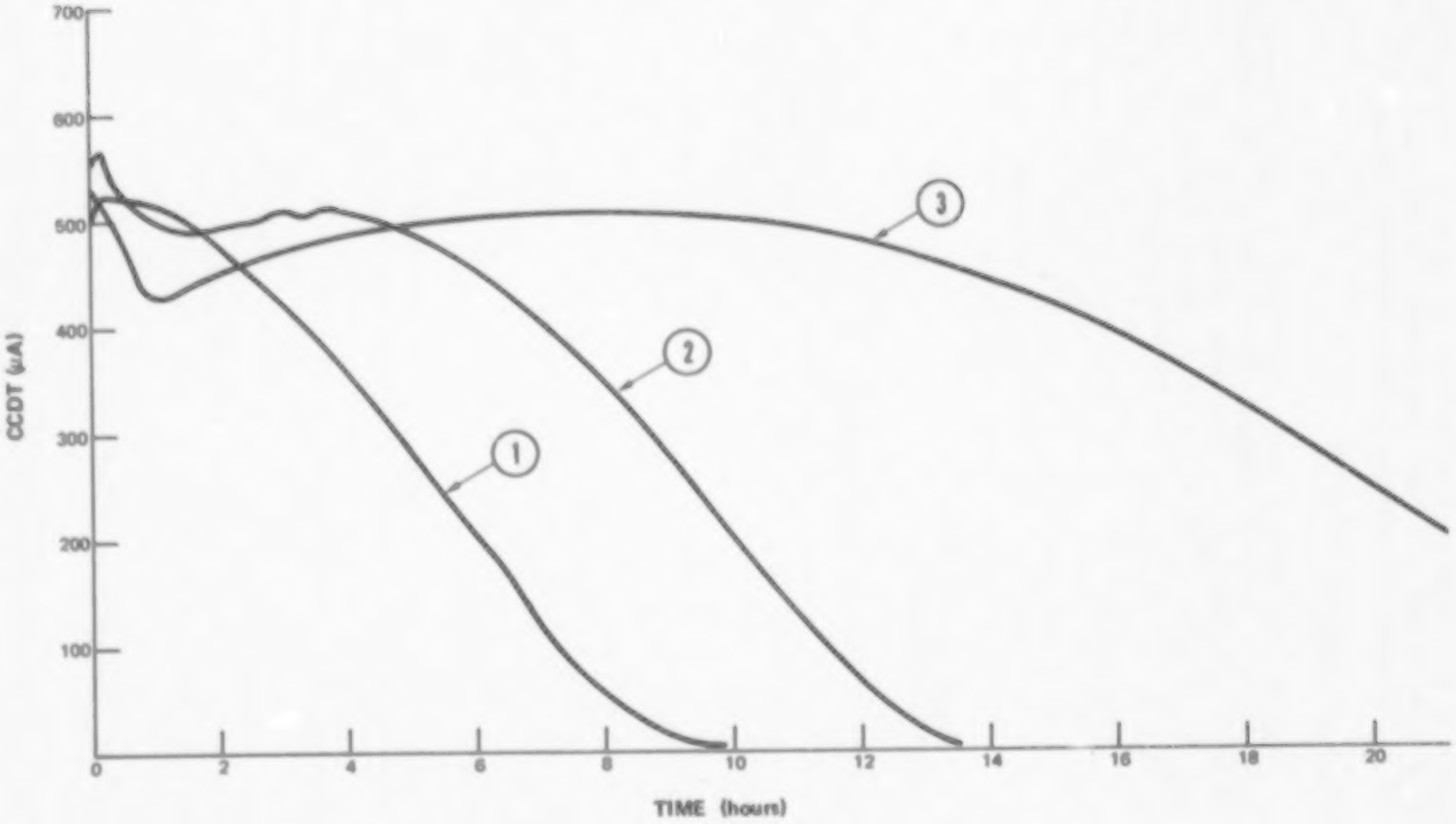


Figure 17. Effect of pH adjustment of blended waters on CCDT.

Curve No.	Date and Time	Water Type	Ca mg/L	Alk. mg/L	EC	CCDT Slope µA/min
1	6/1/78 @ 0803	High % GW	130	195	960	3.8
2	6/1/78 @ 1216	Low % GW	53	91	690	1.4
3	5/31/78 @ 2015	Period when water changed				
		from low GW	53	90	700	1.3
		to high GW	130	200	960	6.7

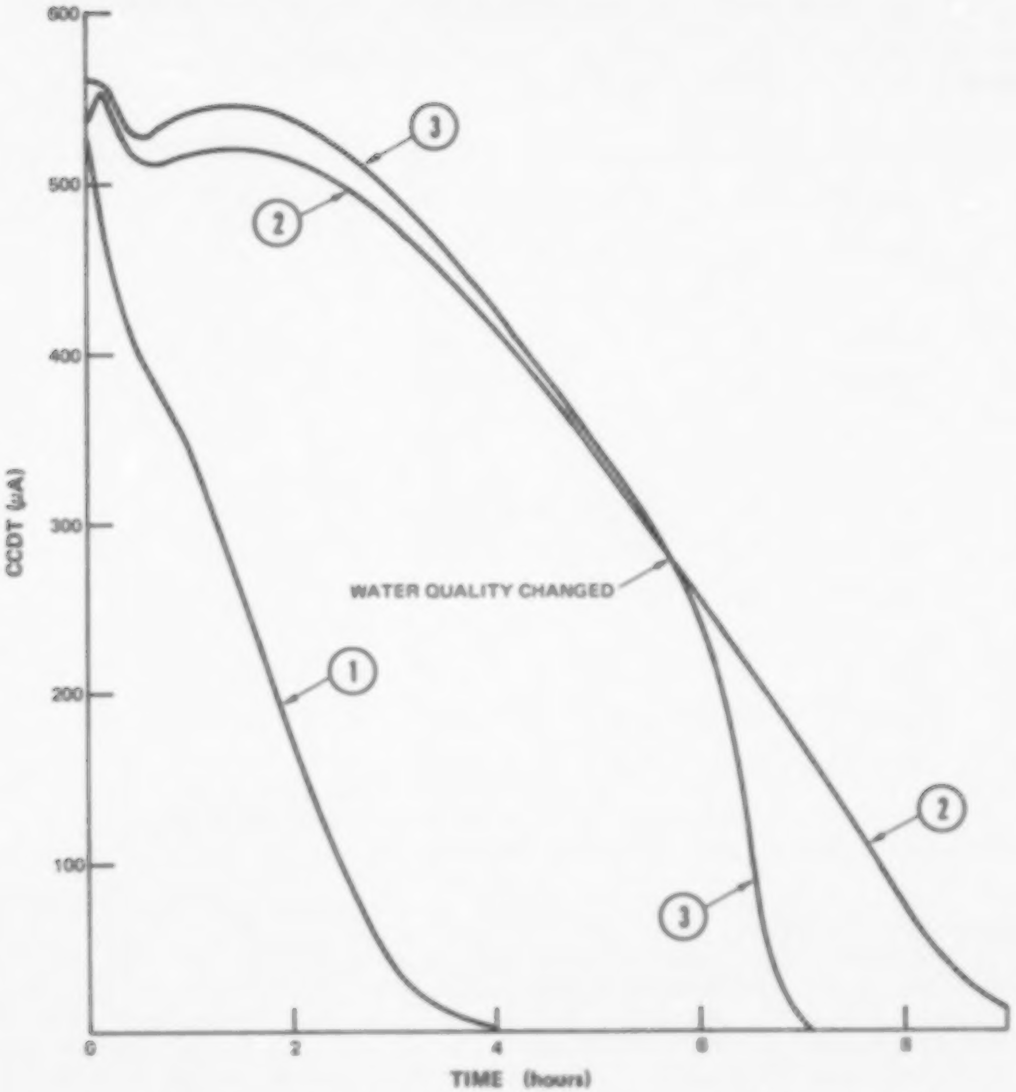


Figure 18. Effect on CCDT due to in-line diurnal changes in source of water at Location 29.

this project. At Long Beach the zinc orthophosphate was prepared by mixing zinc sulfate and orthophosphoric acid on site; whereas, a proprietary formulation sold under the trade name Virchem 932 was used at Alhambra (Location 19) and Walnut Valley Water District (Location 20). Paired comparisons of corrosion rates and CCDT were made on these waters before and after adding the zinc phosphate. A summary of these results are presented in Table 13 and Figure 19 shows the marked effect of the zinc compound on the CCDT.

TABLE 13. COMPARISONS OF CORROSION RATES FOR WATERS WITH AND WITHOUT ZINC ADDED FOR CORROSION CONTROL (7TH DAY CORROSION RATES)

Location Number	Water Type	Zn Added	Zn Conc. mg/L	pH	Anodic Corrosion Rate			CCDT µA/min
					Mild Steel	Zinc	Copper	
3b	CRW/SPW	No	0.02	7.7	7.5*	4.5*	1.0*	2.5
4	CRW/SPW	Yes	1.14	7.5	8.4	3.7	2.0	58
27	CRW/SPW	No	0.01	7.6	7.4	4.9	1.3	0.8
28	CRW/SPW	Yes	0.95	7.4	9.0	5.3	0.9	54
21	CRW	No	0.06	8.2	6.6	2.9	1.8	2
20	CRW	Yes	0.79	8.2	5.7	0.6	1.1	57
19	CRW/GW	Yes	1.46	7.9	6.8#	4.2#	-	61
17	CRW/GW	No	0.12	7.5	7.5#	4.7#	-	9
18	CRW/GW	No	0.03	7.4	8.3#	5.5#	-	6
15	CRW/GW	Yes	0.66	7.4	7.0#	2.8#	-	27

* 8 days from water quality change; 12 days from clean electrodes
# With ground loop in corrosion measuring circuit

The addition of zinc phosphate caused a thin zinc-containing film to form very rapidly on the CCDT electrode which blocked the microcurrent flow in the instrument. The film formation rate ranged from 27 to 61 µA/min. irrespective of the film-forming characteristics of the water prior to adding the corrosion control chemical. Because of the short time, less than 20 minutes to complete a single CCDT run, the amount of material deposited on the electrode was very small. Its exact nature could not be determined, but a qualitative test indicated the presence of precipitated zinc. The amount of corrosion inhibitor added was not the same at all sampling

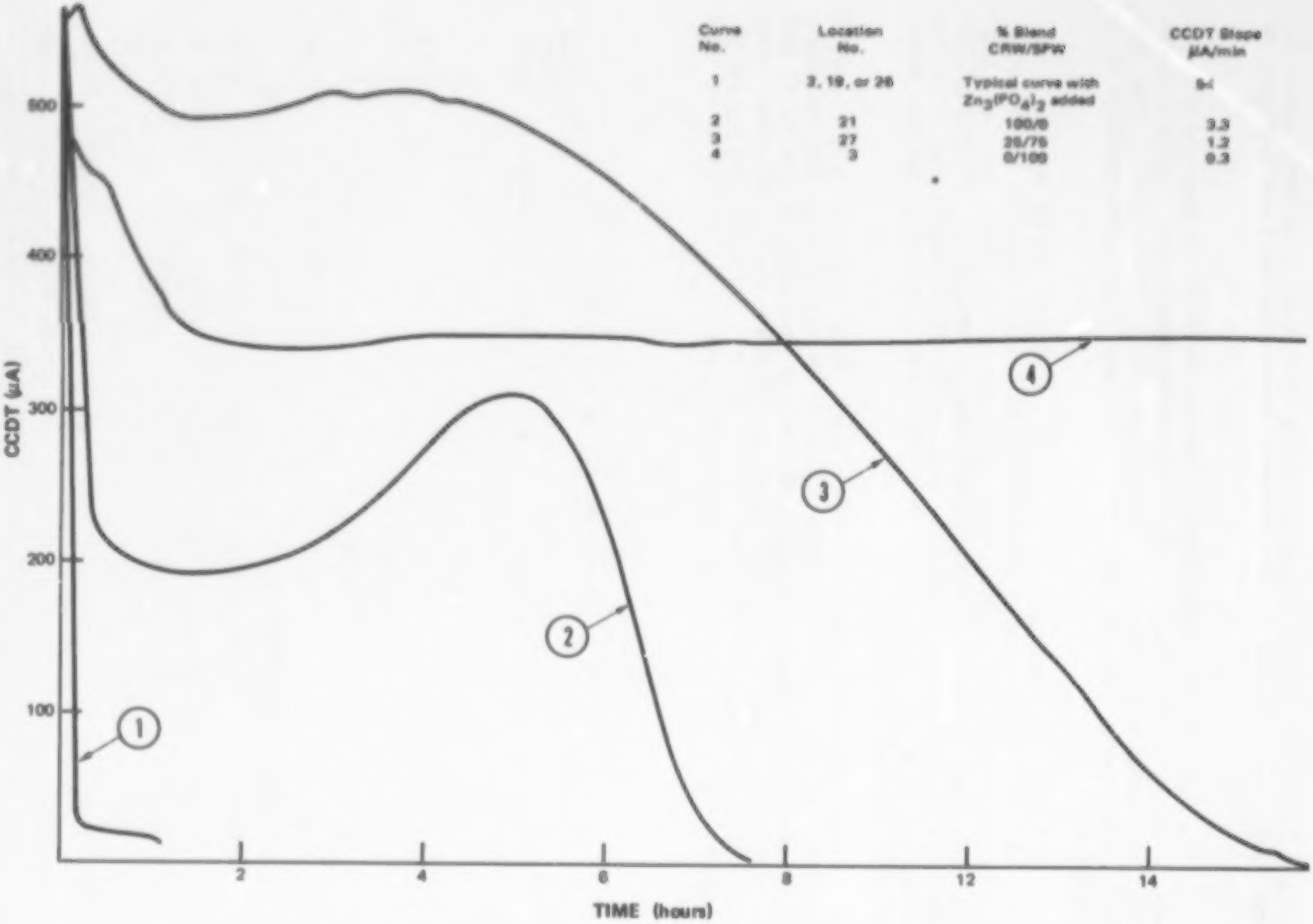


Figure 19. Effect of adding zinc phosphate for corrosion control on CCDT.

locations, Table 14. Those water suppliers that had used MWD water for several years were feeding lesser dosages, equivalent to 1 mg/L of zinc or less.

At Location 19 where MWD water was recently introduced into the system, a zinc level of about 1.5 mg/L was being maintained. Lower dosages caused an upsurge in consumer complaints about "red water," and the chemical was being fed to ease the transition from groundwater to a CRW/GW blend.

Despite the excellent film forming potential shown by the CCDT results, the corrosion rates measured for mild steel exposed to the zinc-treated waters were not significantly different than those for the same quality of water without the corrosion control chemical. Obviously the results of the polarization corrosion test were not in agreement with the "consumer acceptance" parameter, i.e., red water complaints, for the water distributed adjacent to Location 19.

The corrosion rates for zinc metal were more variable. Paired comparisons of zinc corrosion rates in water before adding the corrosion control chemical and after treatment, that is, at Locations 36 and 4, 27 and 28, respectively, showed no difference in corrosion rate. Likewise, when data from Locations 21 and 20, also 18 and 15, respectively, are compared, it appears that the corrosion rates were markedly reduced by the treatment.

TABLE 14. ZINC LEVELS FOR LOCATIONS WHERE ZINC CORROSION INHIBITOR WAS ADDED

Location No.	Date	Water	Zinc mg/L	Location No.	Date	Water	Zinc mg/L
2	2/8/77	SPW	1.04	15	11/7/77	CRW/GW	0.70
	2/9/77		1.09		11/9/77		0.63
	2/10/77		1.27				
	2/11/77		0.99	19*	1/5/78	CRW/GW	1.43
					1/10/78		1.50
4	2/23/77	CRW/SPW	1.18				
	2/24		1.12	20	1/30/78	CRW	0.81
	2/25		1.40		2/1/78		0.80
	2/26		1.08		2/8/78		0.76
	2/27		1.07				
	2/28		1.14	28	5/16/78	CRW/SPW	0.90
	3/1		1.01		5/18/78		1.00

With the limited data available, the corrosion rates for copper did not appear to be appreciably effected by the zinc corrosion control chemical.

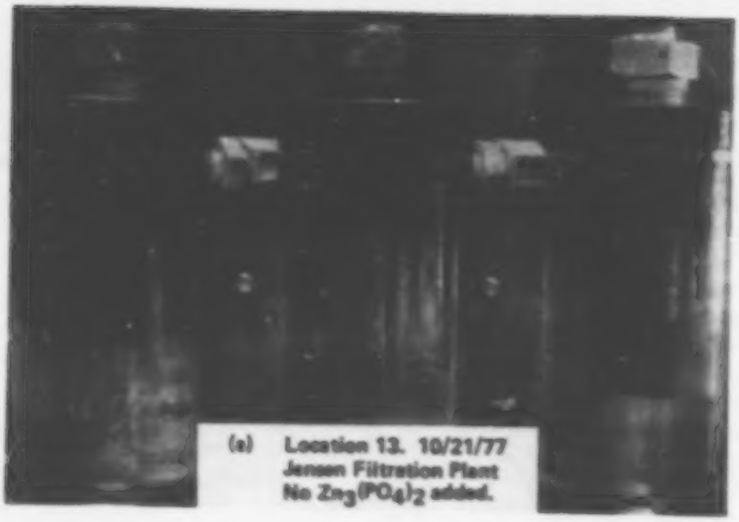
Photographs were taken of the corrosion rate sensors on completion of the tests at all locations. Figure 20 shows sets of the mild steel, zinc and copper electrodes: (a) at Location 13 where no zinc was added and (b) at Location 28 where zinc phosphate was added for corrosion control. In general no specific conclusion concerning differences in the corrosivity of the various waters can be made by observing the appearance of deposits formed on the electrodes in the photographs.

Special arrangements were required to obtain the data at the Long Beach Locations 15-18 because the corrosion control chemicals were added to the groundwater upstream of the point of blending CWR/GW. Zinc phosphate had been fed to the blend of MWD water and very soft groundwater which was then distributed for several years in a large area of Long Beach. A direct comparison of water quality before and after adding the zinc corrosion inhibitor was desired. To accomplish this, a plan was implemented with the cooperation of the Long Beach Water Department staff to discontinue the application of zinc phosphate for six weeks to perform the mobile laboratory tests and to monitor 14 established points in their distribution system for iron content.

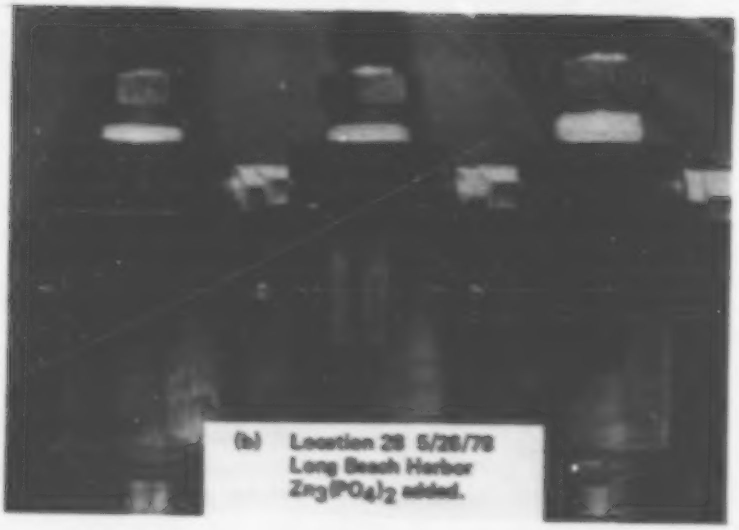
During this temporary cessation of the zinc phosphate treatment, the laboratory staff of the Long Beach Water Department collected and analyzed six sets of samples taken weekly to determine the iron levels. These data are compared in Table 15 with the average iron content of seven sets of samples taken immediately before the above test period. The difference in iron levels for the six-week period after stopping the corrosion control treatment was not significant.

It seems probable that the protective deposits laid down during long-continued application of zinc phosphate may have a carryover effect for several days or weeks after terminating the treatment. For example, a zinc concentration of 0.12 mg/L was noted at Location 17 some three weeks after ceasing to feed the zinc compound. At that same time the zinc background levels in the water supplies were 0.03 mg/L and 0.01 mg/L for Long Beach groundwater and Metropolitan's CRW, respectively. Later at Location 18, there was no evidence of leaching or sloughing of these deposits. Nonetheless, some residual benefits of the films deposited earlier may have persisted for the entire six weeks when no zinc phosphate was being fed. While the data definitely suggest that continuous feeding of zinc phosphate corrosion control chemicals may not be required, a longer cessation of feeding the inhibitor is needed to prove this conclusively.

In the summer of 1978, six months after the mobile laboratory tests at Location 20, the feeding of this corrosion control chemical was discontinued in the service area of the Walnut Valley Water District because of budgetary constraints. Even though they have not conducted an extensive water quality monitoring program, their staff reports that



(a) Location 13. 10/21/77
Jensen Filtration Plant
No $Zn_3(PO_4)_2$ added.



(b) Location 28 5/26/78
Long Beach Harbor
$Zn_3(PO_4)_2$ added.

Figure 20. Photographs of corrosion electrodes.

TABLE 15. IRON IN LONG BEACH DISTRIBUTION WATER

Long Beach Sampling Points	Avg. of 6 samples when Zn feed was off mg/L iron	Avg. of 7 samples when Zn feed was on mg/L iron	Difference in iron when Zn feed was off mg/L iron
1	0.04	0.02	0.02
2	0.03	0.03	0
3	0.02	0.02	0
4	0.03	0.02	0.01
5	0.02	0.02	0
6	0.04	0.03	0.01
7	0.05	0.03	0.02
8	0.02	0.02	0
9	0.02	0.02	0
10	0.03	0.03	0
11	0.02	0.02	0
12	0.04	0.03	0.01
13	0.06	0.05	0.01
14	0.08	0.07	0.01

consumer acceptance of the water has remained good with no appreciable rise in corrosion complaints.

CORROSION COUPON TESTS

Mild steel coupons placed in the water received at Walnut Valley Water District in April 1977 (CRW) before and after treatment with the corrosion control chemical indicated a 16 percent reduction in corrosion rate after adding the zinc compound. Coupons exposed in August 1978 to a blend of CRW/SPW showed no difference in corrosion rates after treatment with zinc phosphate. Thus, the coupon tests appeared to confirm the consumer observations.

Similar tests performed in June and July 1976 by the Long Beach Water Department staff indicated the great influence of flow rates through the corrosion cell on the results:

	Corrosion Rate		
Flow Rate	No zinc or phosphate	With zinc and phosphate	Percent Reduction
8.0-8.6 f.p.s.	2.9 mils/yr.	1.2 mils/yr.	59
0.05 f.p.s.	12.0 mils/yr.	11.0 mils/yr.	8.3

Duration of these tests was four to five weeks. These results are presented to show the complexity of the problem when one attempts to evaluate the benefits of a corrosion control procedure. Obviously, flow rates must be taken into account on coupon tests just as was found to be true for the polarization corrosion rates measured on-board the mobile laboratory.

Corrosion rates were determined at Alhambra on coupons of SAE 1018 mild steel exposed for 65 days to various blends of Colorado River and State project water during the period from November 1977 to December 1978. The tests were performed by the producer of Virchem 932 inhibitor. Corrosion rate reductions of 90-94 percent were reported for the water treated with the corrosion inhibitor. Unfortunately, the flow rates past the coupons exposed to untreated water were not the same as for the treated water. Consequently, the magnitude of the beneficial effect is more qualitative than quantitative, but it agrees with consumer acceptance reported in this distribution system where surface water from MWD is being blended with the local groundwater.

INTERRELATIONS BETWEEN CCDT AND OTHER WATER QUALITY PARAMETERS

The effects of calcium hardness, alkalinity, pH and zinc phosphate on the CCDT measurements have indicated some definite correlations for several of the waters discussed in the above sections. The usefulness of CCDT as a general parameter to characterize the stability or corrosivity of a water will depend on its relation to other water quality parameters. To look for such interrelations for all the waters studied, the CCDT data were plotted against the calcium and alkalinity levels in Figure 21, against the polarization corrosion rates for mild steel and zinc in Figure 22, and against the Langelier index and the Ryzner index in Figure 23. All of these figures illustrate the marked effect of zinc orthophosphate on accelerating film formation as measured by CCDT. Consequently, those few points must be considered as a separate group in the ensuing discussion.

A strong trend toward higher CCDT values was associated with increases in calcium content and alkalinity of the southern California waters studied (Figure 21). This was not unexpected since the theory of calcium carbonate film formation is based on calcium hardness, alkalinity and pH.

McClelland and Mancy (5,15) measured the scaling characteristics of tap water from a number of Michigan cities by the CCDT method. On the basis of their data, they suggested guidelines for interpreting the scaling potential of waters by this test. With CCDT values >3, waters

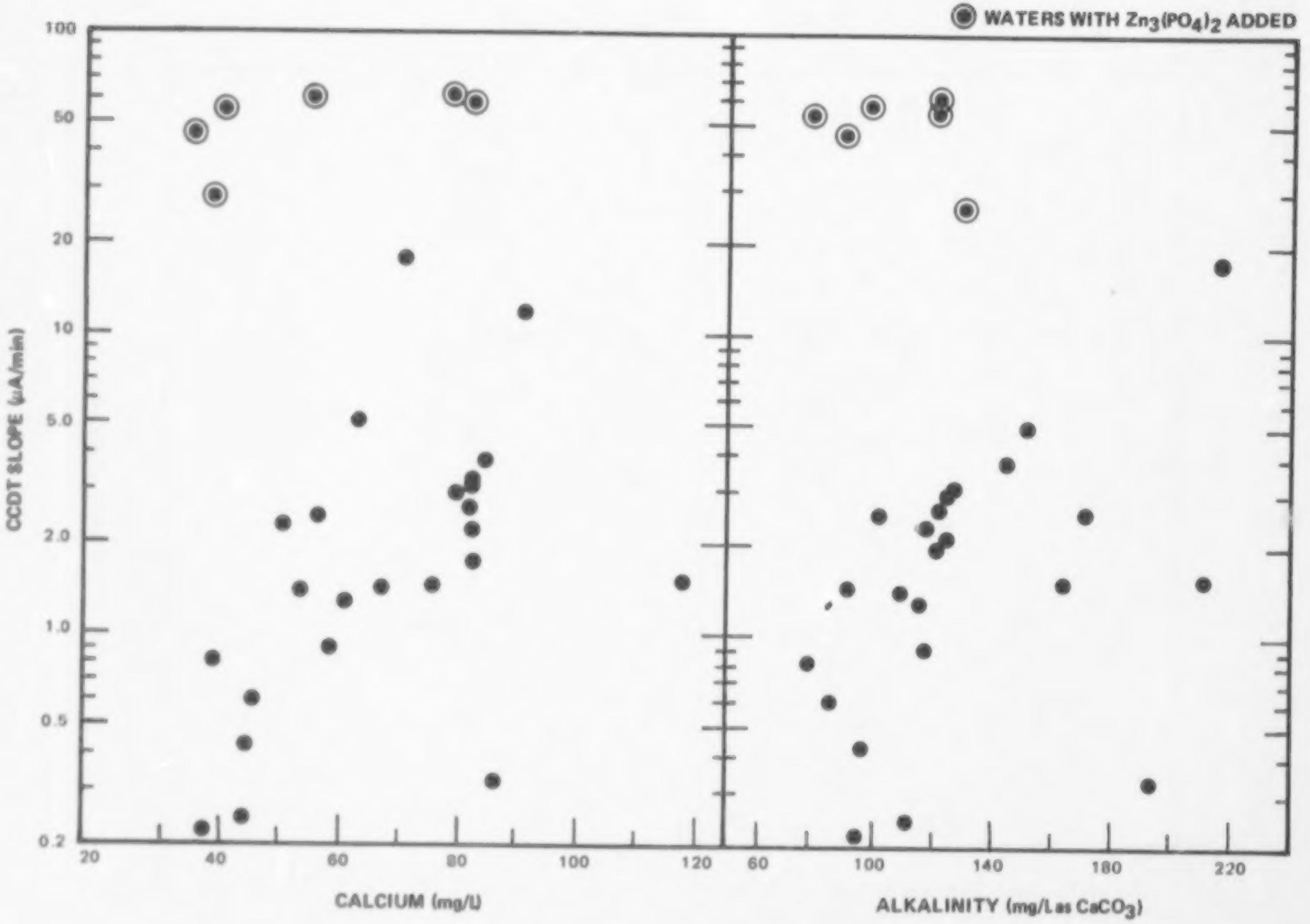


Figure 21. CCDT results vs. calcium and alkalinity levels.

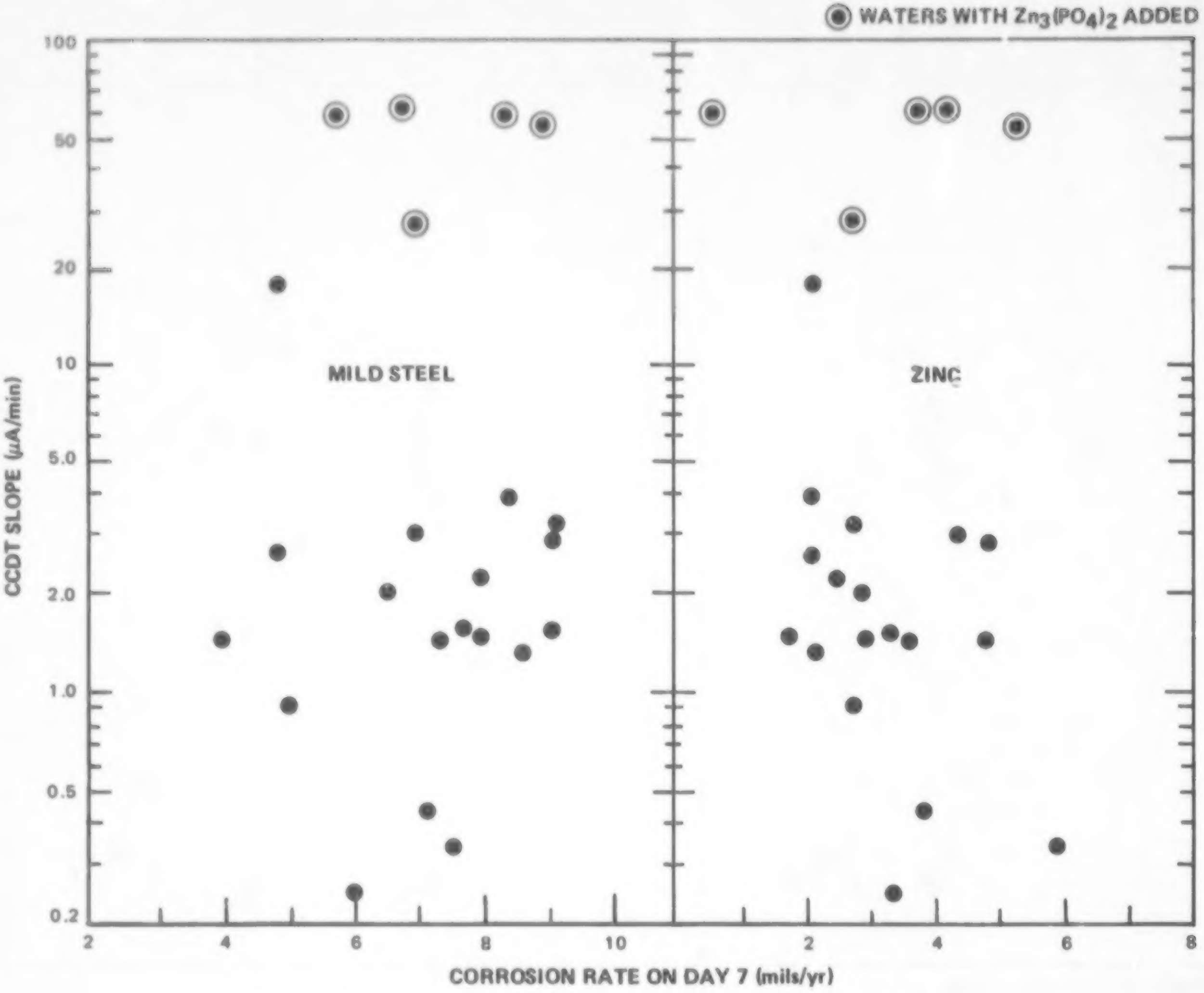


Figure 22. CCDT results vs. corrosion rates for mild steel and zinc on day 7.

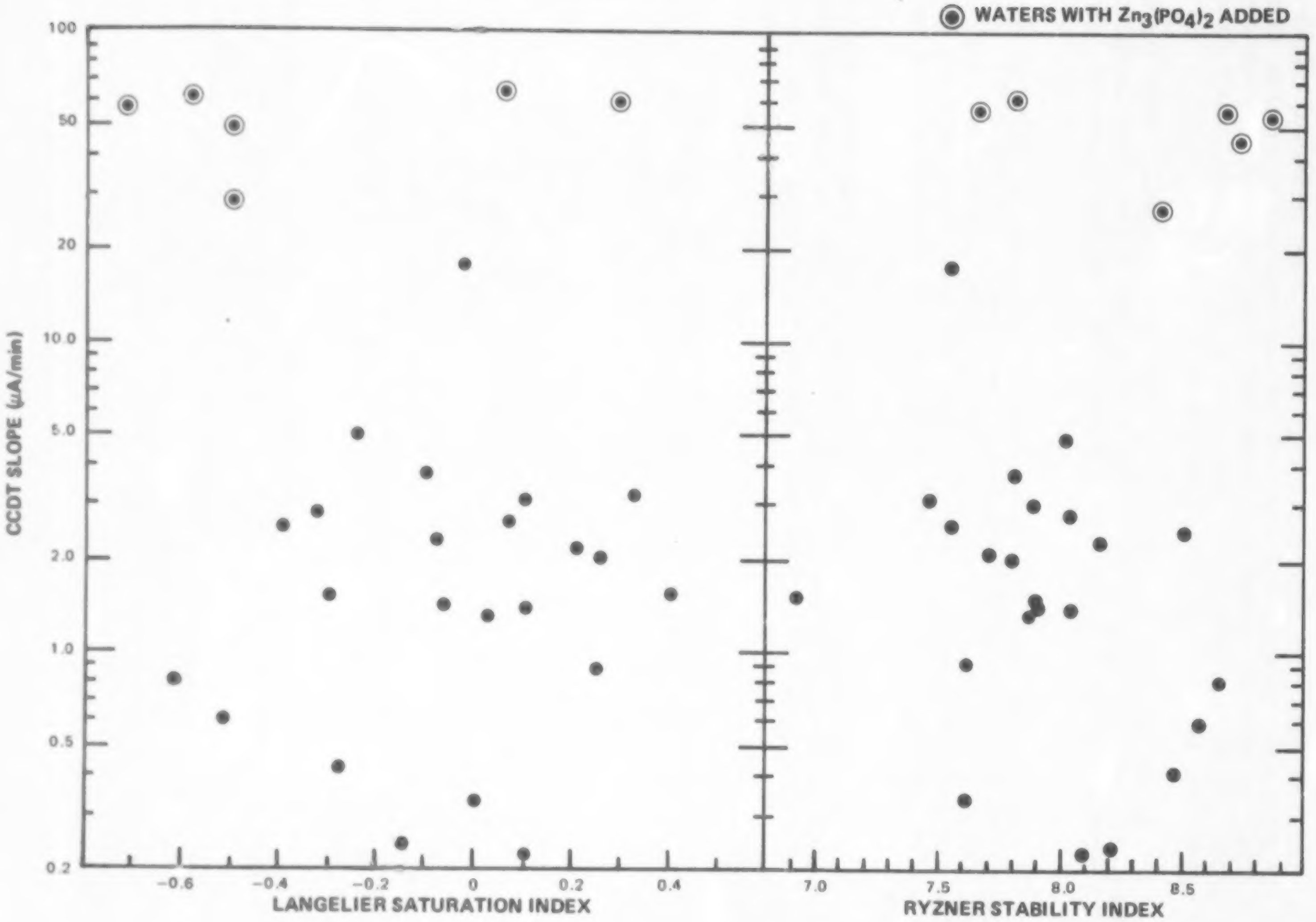


Figure 23. CCDT results vs. Langelier and Ryzner indices.

known to form films that reduce carrying capacity were indicated. Waters with CCDT values between 0.2 and 0.75 can be expected to produce thin hard films of calcium carbonate, which will effectively protect against corrosion. Waters showing CCDT values >0.75 but <3.0 may cause films to be deposited which will, in time, affect carrying capacity.

Excluding those waters treated with zinc phosphate, only three waters were found to have CCDT values >3.0 in this study. Five locations had measured CCDT values between 0.2 and 0.75, and none was less than 0.2.

We believe that the data obtained from this project and the previous study by McClelland and Mancy have shown that the CCDT is a very useful parameter for evaluating film formation potential of drinking water supplies. Nonetheless, additional data on many types of water are needed to develop more meaningful guidelines for interpretation of the results.

For the waters not treated with the zinc compound, there was no evidence of an inverse relation between the corrosion rate for mild steel and CCDT values (Figure 22). There was, however, a moderate inverse trend between corrosion rates for zinc and the CCDT measurements as also shown in Figure 22.

When the CCDT data were plotted against the Langelier index, Figure 23, the points were quite scattered and there was only slight evidence of a relationship between these parameters for the types of waters studied in this area.

In general, CCDT results plotted against the Ryzner index showed lower CCDT values correlated with high Ryzner indices in Figure 23. This should be expected since higher Ryzner indices indicate an increase in the calcium carbonate dissolving tendency and low CCDT values indicate slight to moderate rates of calcium carbonate deposition. The impirical Ryzner index was devised to assign a greater influence to the calcium content of a water than the Langelier index. These data would indicate that Ryzners's modification to the Langelier index has made it more sensitive to the calcium carbonate deposition tendency as measured by the CCDT method.

It is interesting to note that the great impact of the zinc phosphate treatment on CCDT did not cause a cluster of points with lower corrosion rates for mild steel and zinc. This failure of the monitored corrosion rate for mild steel to be reduced was also pointed out when discussing paired data for the same quality of water before and after adding the corrosion control chemical. Other investigators have suggested the need for coupon tests and observations of metallic ion pick-up in the distribution system as a means of overcoming the inadequacies of the various instantaneous or accelerated corrosion parameters.

RESPONSE OF MONITORING SYSTEMS TO QUALITY CHANGES

The mobile laboratory monitoring systems afford an excellent means of detecting quality changes in a distribution system. They have the capability of responding to those differences in water quality which can then be used to make qualitative comparisons of the relative stability and/or corrosiveness of waters blended in a distribution system.

This capability of sensing changes can be seen in typical portions of the graphs plotted from data recorded by the laboratory computer at Locations 25 (Figures 7 and 8) and 29 (Figures 24 and 25). The well water pumped into the distribution system had a much higher alkalinity than the blend of CRW/SPW being delivered to Location 25, but there was little difference in the hardness of the two waters. At Location 29, both the hardness and alkalinity of the well water was much higher than in the CRW/SPW blend.

Whenever a high percentage of groundwater arrived at Location 25 lower readings were observed on polarization corrosion rates for mild steel and zinc but slightly higher rates were recorded for copper. The latter response is probably due to the higher free carbon dioxide content, 14 mg/L, and lower pH of the well water. The corrosion rates during the periods when a low percentage of groundwater was present are designated in Table 8 as Location 25a; the rates for the high percentage of groundwater are shown as Location 25b. During the 9 hours each day when the blend contained the minimal amount of well water, about 11 percent, the corrosion rates for mild steel and zinc were higher than for either the CRW/SPW delivered by MWD (Table 8, Location 23) or the groundwater (Location 24) when fed continuously to the corrosion rate cells.

Because it is probable that the electrode surfaces were conditioned by each cyclic change in water quality, one must question the significance of the numerical values for the corrosion rates under each set of conditions. Nonetheless, the values do point up directional tendencies which indicate that one water may be more or less aggressive than another to a particular metal in the distribution system. The data also provide some support to observations that constant changing of water quality in a water system may often be less desirable than using one water continuously for long periods of time irrespective of the qualities of each.

The strip chart in Figure 25 for Location 29 is presented principally to show the effect of changing both hardness and alkalinity on the CCDT slope and on corrosion rate curves. The automatic cut-off and start-up of the CCDT system enabled the collection of data on these diurnal changes that was not available at the onset of this study.

When the well water with higher alkalinity and hardness than the CRW/SPW blend reached the laboratory at Location 29, the corrosion rate for zinc decreased significantly though not as much as at Location 25 where the well water alkalinity was nearly twice that of MWD's blended water.

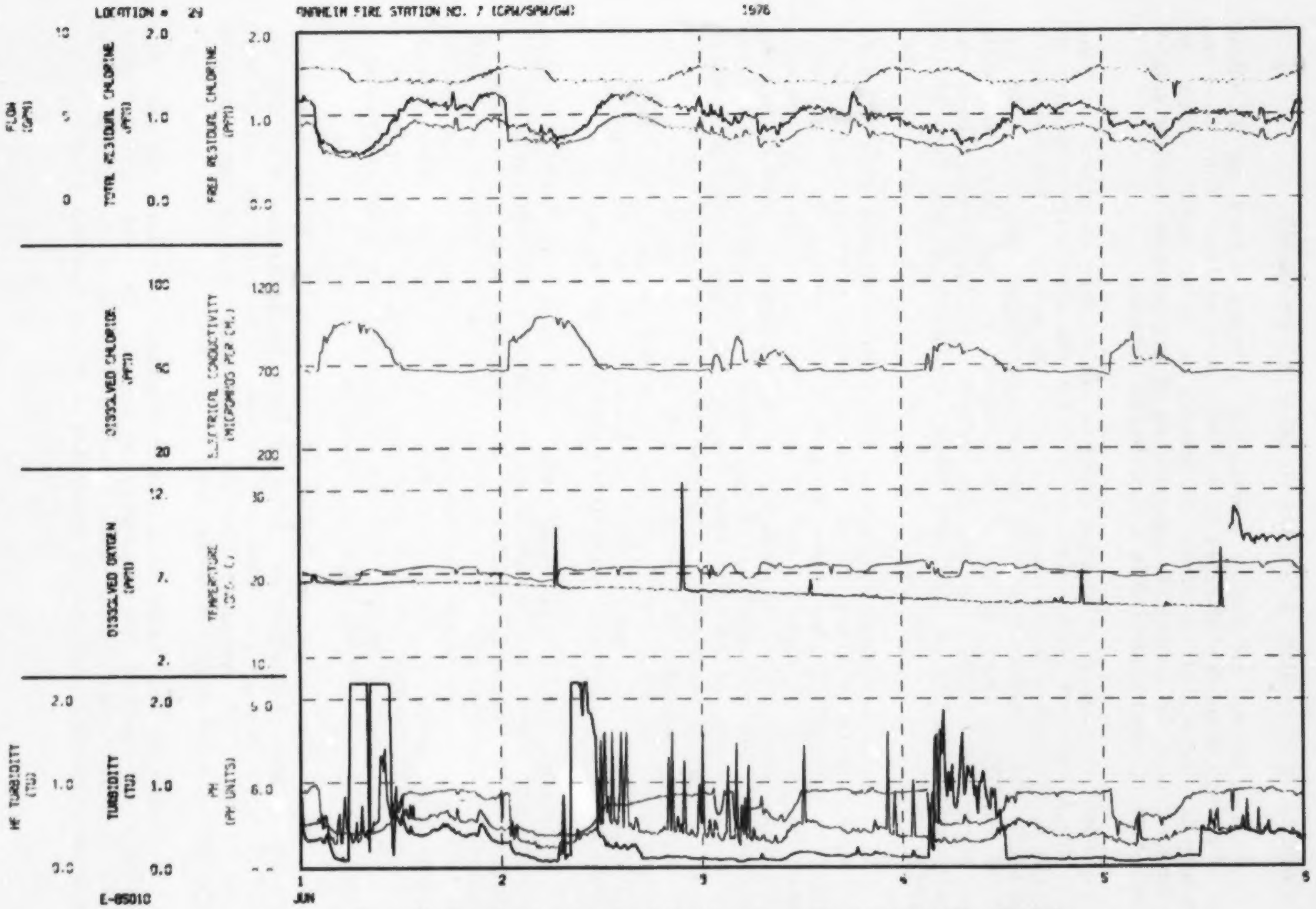


Figure 24. Data showing diurnal variations in water quality at Location 29 — Graph A.

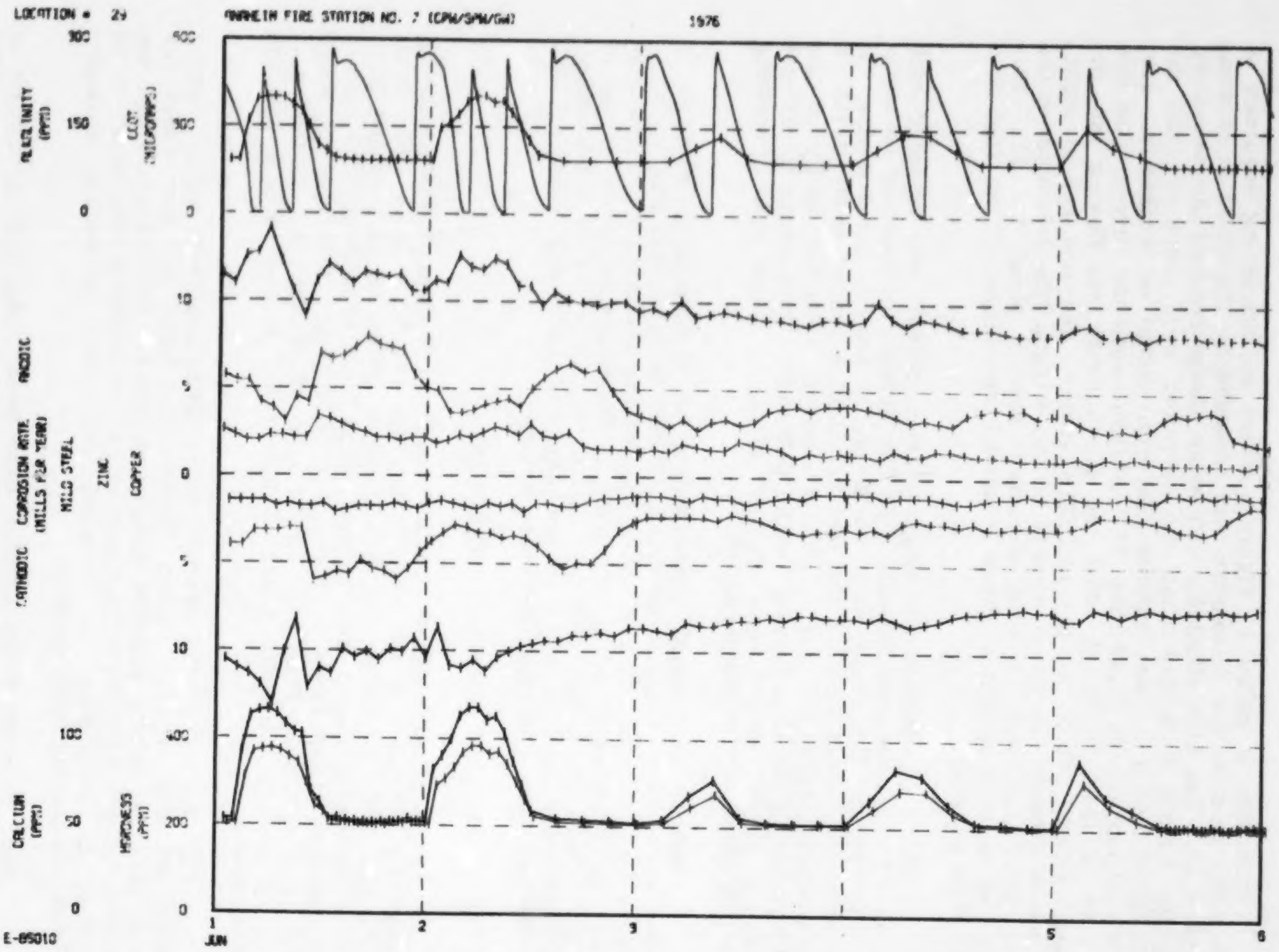


Figure 25. Data showing diurnal variations in water quality at Location 29 – Graph B.

Attention is called to Figure 8 where an interesting sequence of film formation and partial dissolution was recorded by the CCDT instrument at Location 25. The high alkalinity well water always reached the laboratory during the normal work day when the operators were there to clean the rotating gold disc and start another test run except on weekends. Film formation occurred at a rapid rate, 17.8 μA/min, until the current flow was diminished to about 50-60 μA when the groundwater was flowing into the sampling system. Then, as the CWR/SPW entered the test cell at night, there was a decrease in the continuity of the original film deposited on the rotating disc, sufficient to allow a current flow of about 110 μA. This increase in current indicates either a partial dissolution of the film or a change in its porosity.

This cyclic pattern for single 24-hour periods was repeated each day after cleaning the rotating disc. In the absence of cleaning on weekends, the current flow dropped to 15-20 μA on April 1 and 2 during the hours when well water entered the test cell and increased to about 110 μA again at night when the surface water arrived. Further study of the characteristics of the film formed by the well water which seems to dissolve partially on contact with a water of lower alkalinity might yield interesting information on protective film formation.

Changes in fluoride concentration by a planned interruption in operation of chemical feeders were used by McClelland and Mancy (5) to determine the residence time of water in portions of Chicago's distribution system. In the present study, changes in concentration levels of one or more parameters, such as, alkalinity, hardness, chlorides or conductance, could have been used to trace the movement of local well water or MWD water through several of the distribution systems.

COSTS OF CORROSION CONTROL TREATMENT

The most widespread practice employed to improve water quality by mitigating corrosion is pH adjustment with caustic soda or lime. MWD uses caustic soda to offset the pH lowering effect of alum added as a coagulant during treatment and chlorine added for disinfection. The cost of pH adjustment varies from an average of $0.55 per acre foot of water treated to a maximum of $1.52. The dosage of caustic soda is varied to maintain a positive Langelier Index of 0.1 to 0.2 as the water leaves the filtration plants.

Blending of MWD's treated water with local well waters having moderate amounts of free carbon dioxide and lower pH may cause the blended water to have a negative saturation index. Several years ago the application of pH adjustment chemicals in a few systems was found to be efficacious in stabilizing the blended water and minimizing consumer complaints concerning water quality.

More recently three utilities have been using zinc phosphate to stabilize pipeline deposits and to minimize "red water" occurrences. The annual cost of the treatment chemicals at Long Beach, Walnut Valley Water District, and Alhambra is about $100,000, $47,000 and $20,000, respectively.

Unit costs were \$1.57, \$3.91 and \$6.56 per acre-foot of water treated in each of these distribution systems, respectively. Because these costs are considerably higher than the cost of pH adjustment and must be added to the overall cost, each utility is concerned about more economical means of achieving adequate corrosion control in their system.

As pointed out earlier, the addition of zinc phosphate certainly enhances film formation as measured by CCDT, but the comparative polarization corrosion rates were not conclusive in support of a benefit therefrom. In view of the persistence of zinc in the Long Beach system for some three weeks after cessation of zinc phosphate feed, a program of intermittant feeding of the corrosion inhibitor is suggested to reduce costs.

To further define such a feeding program: the present chemical application should be cut off completely for a period of 4 to 6 weeks; and, then, the chemical should be fed continuously for 4 to 6 weeks. This cycle should be repeated until monitoring of iron and zinc content at representative sampling points indicate that longer or shorter on- and off-periods result in optimum stabilization of water quality at minimum cost. The possibility that the most desirable off-period may be longer than the on-period should not be overlooked.

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APPENDIX A

DAQ PROGRAM LISTING
DATA ACQUISITION WORKER TASK
(As Modified by MWD--Modifications Only)

```
LOC    OBJECT                            SOURCE

1530  0006         SIX
1531  0000         CNTR
1532  000A         TIME
1533  0000         TIME1
 .
 .
 .
16F1  15AF 9012    INIT            MOV   ZERO,FG
16F3  1430 9031                    MOV   SIX,CNTR
16F5  15AF 9033                    MOV   ZERO,TIME1
16F7  3406 0000                    SETB  D06,0
16F9  3407 0000                    SETB  D07,0
16FB  3408 0000                    SETB  D08,0
16FD  3409 0000                    SETB  D09,0
16FF  340A 0800                    SETB  DOA,1
1701  340B 0000                    SETB  DOB,0
1703  340C 0000                    SETB  DOC,0
1705  340F 0000                    SETB  DOF,0
1707  7082 1749                    B     CCDT
 .
 .
 .
1711  1C14 8140   WAIT             CMI   AD1,320
1713  7082 171D                  < B     COUNT
1715  7082 1719                  > B     CNTUE
1717  7082 171D                  = B     COUNT
1719  1430 9031   CNTUE            MOV   SIX,CNTR
171B  7082 1725                    B     HOLD
171D  4401 1531   COUNT            L     1,CNTR
171F  OC1F 1723                    ARB   -1,STORE,1
1721  7082 1749                    B     CCDT
1723  4881 1531   STORE            ST    1,CNTR
1725  4400 1532   HOLD             L     0,TIME
1727  5080 0001                    SA    0,1
1729  4880 1533   HOLD1            ST    0,TIME1
172B  4483 31AB                    LA    3,X'3000'+@DEL2
172D  7980 007F                    SXBS  *127
```

```
172F  0C0F 1729          ARB   -1,HOLD1,0
1731  3008 0878  TEST    BBNE  DI8,1,OPEN
1733  340A 0800  CLOSE   SETB  DOA,1
1735  7082 1739          B     READ
1737  340A 0000  OPEN    SETB  DOA,0
1739  4483 31A9  READ    LA    3,X'3000'+@DEL0
173B  7980 007F          SXBS  *127
173D  7882 178F          SSB   SRTA
173F  340F 0800          SETB  DOF,1
1741  4483 31A9          LA    3,X'3000'+@DEL0
1743  7980 007F          SXBS  *127
1745  340F 0000          SETB  DOF,0
1747  7082 184C          B     FINI
1749  340A 0800  CCDT    SETB  DOA,1
174B  7482 1830          BL    2,HOLD2
174D  340C 0800          SETB  DOC,1
174F  7482 1830          BL    2,HOLD2
1751  3409 0800          SETB  DO9,1
1753  7482 1830          BL    2,HOLD2
1755  3408 0800          SETB  DO8,1
1757  4483 31AC          LA    3,X'3000'+@DEL3
1759  7980 007F          SXBS  *127
175B  3408 0000          SETB  DO8,0
175D  7482 1830          BL    2,HOLD2
175F  3407 0800          SETB  DO7,1
1761  7482 1830          BL    2,HOLD2
1763  340B 0800          SETB  DOB,1
1765  4483 31AC          LA    3,X'3000'+@DEL3
1767  7980 007F          SXBS  *127
1769  340B 0000          SETB  DOB,0
176B  4483 31A9          LA    3,X'3000'+@DEL0
176D  7980 007F          SXBS  *127
176F  340C 0000          SETB  DOC,0
1771  4483 31A9          LA    3,X'3000'+@DEL3
1773  7980 007F          SXBS  *127
1775  340B 0800          SETB  DOB,1
1777  4483 31AC          LA    3,X'3000'+@DEL3
1779  7980 007F          SXBS  *127
177B  340B 0000          SETB  DOB,0
177D  7482 1830          BL    2,HOLD2
177F  3407 0000          SETB  DO7,0
1781  7482 1830          BL    2,HOLD2
1783  3409 0000          SETB  DO9,0
1785  7482 1830          BL    2,HOLD2
1787  3406 0800          SETB  DO6,1
1789  7082 17CA          B     CONTUE
 .
 .
 .

(178F - 17C9  SRT A)
```

```
 .
 .
 .
17CA  4483 31A9  CONTUE                    LA    3,X'3000'+@DEL0
17CC  7980 007F                             SXBS  *127
17CE  340B 0800                             SETB  DOB,1
17D0  4483 31AE                             LA    3,X'3000'+@DEL5
17D2  7980 007F                             SXBS  *127
17D4  340B 0000                             SETB  DOB,0
17D6  7482 1830                             BL    2,HOLD2
17D8  340C 0800                             SETB  DOC,1
17DA  4483 31A9                             LA    3,X'3000'+@DEL0
17DC  7980 007F                             SXBS  *127
17DF  340B 0800                             SETB  DOB,1
17E0  4483 31AB                             LA    3,X'3000'+@DEL2
17E2  7980 007F                             SXBS  *127
17E4  340B 0000                             SETB  DOB,0
17E6  7482 1830                             BL    2,HOLD2
17E8  340C 0000                             SETB  DOC,0
17EA  7482 1830                             BL    2,HOLD2
17EC  3406 0000                             SETB  D06,0
17EF  4400 1532                             L     0,TIME
17F0  1C32 8009                             CMI   TIME,9
17F2  7082 1731                           < B     TEST
17F4  7007 0000                           > NOP
17F6  5080 0009                           = SA    0,9
17F8  7082 1729                             B     HOLD1
 .
 .
 .
1830  4480 0000  HOLD2                      LA    0,0
1832  0C02 1832                             ARB   2,$,0
1834  72A2 0002                             B     2,2
 .
 .
 .
184E  8400 0852                             BFNE  (0,0),1,WAIT
```

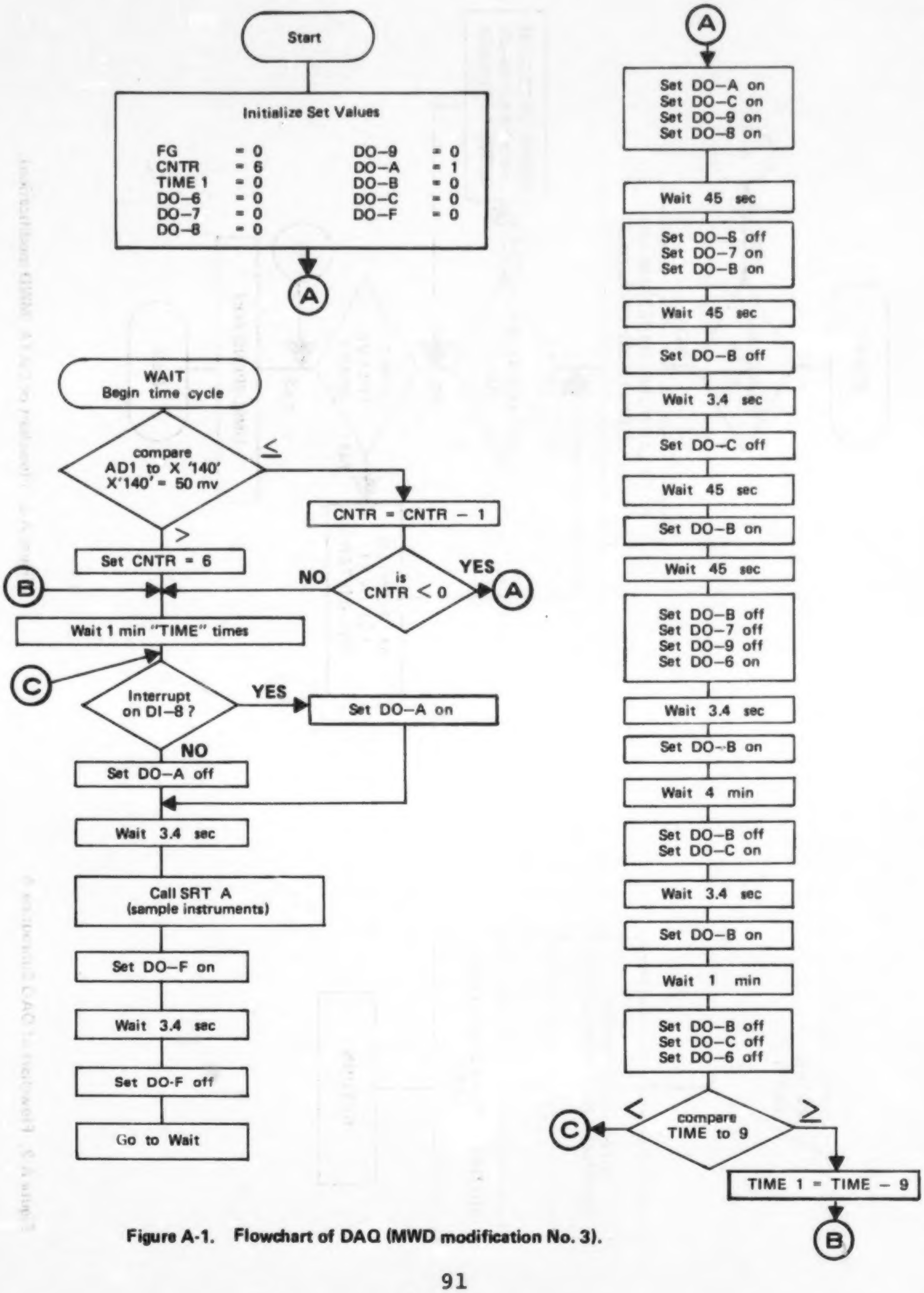
Start
Initialize Set Values
FG = 0
CNTR = 6
TIME 1 = 0
DO–6 = 0
DO–7 = 0
DO–8 = 0
DO–9 = 0
DO–A = 1
DO–B = 0
DO–C = 0
DO–F = 0
A
WAIT
Begin time cycle
compare
AD1 to X '140'
X'140' = 50 mv
≤
>
CNTR = CNTR – 1
Set CNTR = 6
NO
is
CNTR < 0
YES
A
B
Wait 1 min "TIME" times
C
Interrupt
on DI–8 ?
YES
Set DO–A on
NO
Set DO–A off
Wait 3.4 sec
Call SRT A
(sample instruments)
Set DO–F on
Wait 3.4 sec
Set DO-F off
Go to Wait
A
Set DO–A on
Set DO–C on
Set DO–9 on
Set DO–8 on
Wait 45 sec
Set DO–8 off
Set DO–7 on
Set DO–B on
Wait 45 sec
Set DO–B off
Wait 3.4 sec
Set DO–C off
Wait 45 sec
Set DO–B on
Wait 45 sec
Set DO–B off
Set DO–7 off
Set DO–9 off
Set DO–6 on
Wait 3.4 sec
Set DO–B on
Wait 4 min
Set DO–B off
Set DO–C on
Wait 3.4 sec
Set DO–B on
Wait 1 min
Set DO–B off
Set DO–C off
Set DO–6 off
<
C
compare
TIME to 9
≥
TIME 1 = TIME – 9
B

Figure A-1. Flowchart of DAQ (MWD modification No. 3).

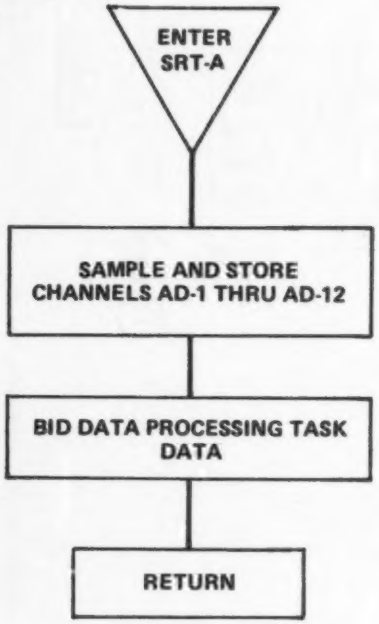
ENTER
SRT-A
SAMPLE AND STORE CHANNELS AD-1 THRU AD-12
BID DATA PROCESSING TASK DATA
RETURN

Figure A-2. Flowchart of DAQ Subroutine A.

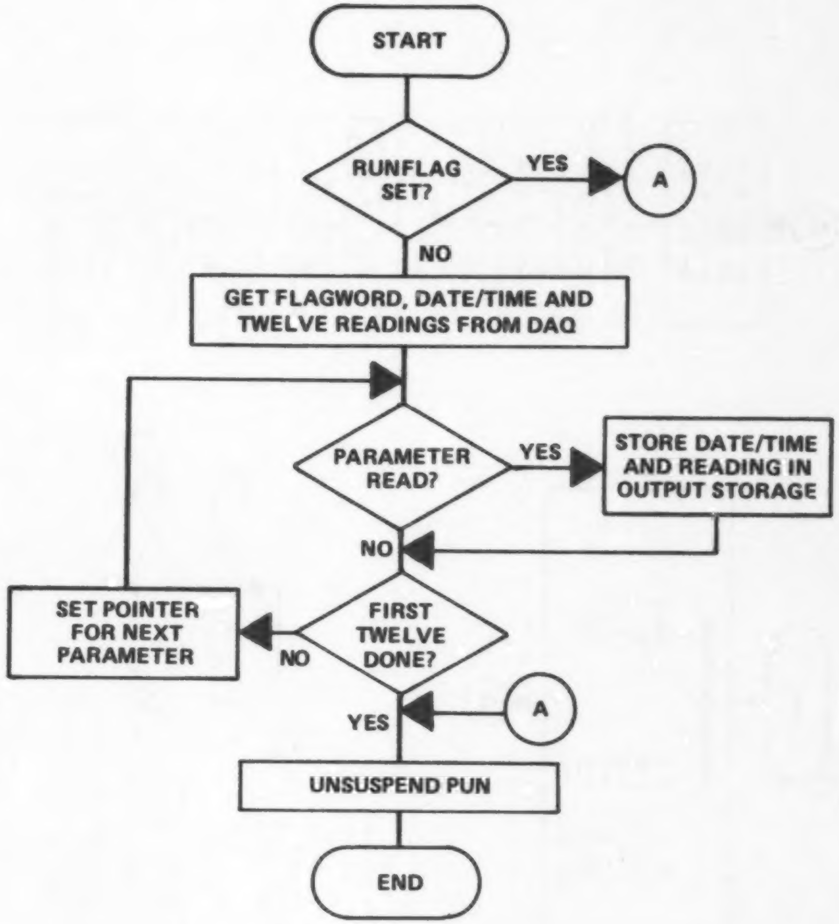
START
RUNFLAG SET?
YES
A
NO
GET FLAGWORD, DATE/TIME AND TWELVE READINGS FROM DAQ
PARAMETER READ?
YES
STORE DATE/TIME AND READING IN OUTPUT STORAGE
NO
FIRST TWELVE DONE?
NO
SET POINTER FOR NEXT PARAMETER
A
YES
UNSUSPEND PUN
END

Figure A-3. Flowchart of DATA (MWD modification).

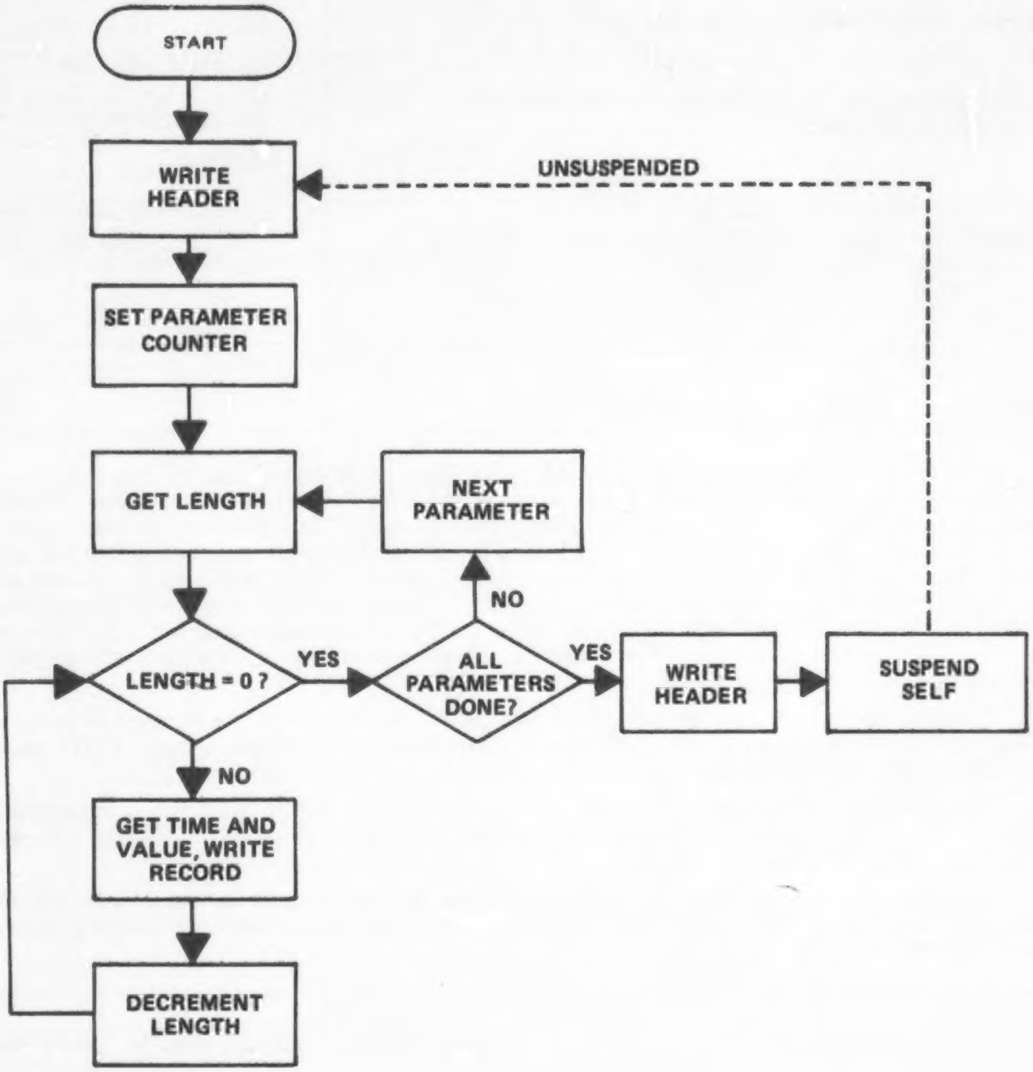
START
WRITE HEADER
UNSUSPENDED
SET PARAMETER COUNTER
GET LENGTH
NEXT PARAMETER
NO
LENGTH = 0 ?
YES
ALL PARAMETERS DONE?
YES
WRITE HEADER
SUSPEND SELF
NO
GET TIME AND VALUE, WRITE RECORD
DECREMENT LENGTH

Figure A-4. Flowchart of PUN.